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SELECTIVE FLOCCULATION STUDIES ON MINERAL SYSTEMS RELEVANT TO INDIAN IRON ORES

By

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SELECTIVE FLOCCULATION STUDIES ON MINERAL SYSTEMS RELEVANT TO INDIAN IRON ORES

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CERTIFICATE

Certified that the present work entitled 'Selective Flocculation Studies on Mineral Systems Relevant to Indian Iron Ores' by Jay Prakash Sharma has been carried out under my supervision and has not been submitted elsewhere for the award of a degree.

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- J.P. Sharma

ABSTRACT

Studies have been made on selective flocculation of pure hematite from pure clay minerals such as kaolinite, montmorillonite, and illite which are the principal constituents in many high-alumina iron ore deposits in India. Particle size ranges chosen were 1-8, 0-2 as well as 2-20 and 5-20 µm. Starch was used as the flocculant. The principal factors studied were made of preparation and concentration of starch solution, concentration of dispersants and other modifiers, pH, number of stages of flocculation etc.

The best results obtained 78 pct. grade (pct. hematite) 78 pct. recovery, Selectivity Index 3.58 are better than those for complex Barsua ore slime and yet not good enough. There is scope for further research on selective dispersants, depressants and flocculants pertaining to hematite-clay systems, the complexities of which have been discussed.

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CHAPTER I

INTRODUCTION

Indian iron ores have high percentages in aluminium which cause difficulties in blast furnace operation. A project was undertaken at I.I.T., Kanpur regarding beneficiation of high-alumina iron ore fines by selective flocculation. Two reports[1a,2] and one paper[1b] are available on the subject. It has been reported[1a,b] that Indian hematite iron ores contain aluminium in the forms of 0.03 to 2.0 mμ grains of clay minerals such as kaolinite, Illite, Montmorillonite etc.

Selective flocculation has been considered to be one of the most promising avenues for beneficiating fine particles. Read and Hollick have provided an useful review[3] regarding the underlying principles and commercial applications of this beneficiation technique. Basically, this involves selective bridging of similar particles by macromolecular flocculants with polar groups, through adsorption, to produce flocs. Some basic studies have been made on binary systems of pure minerals and their separability by selective flocculation[4-10]. Some selectivity data are given in the adjoining summary Table I. Selectivity Index is the geometric mean of $(\frac{R_{vc}}{100-R_{vc}})$ and $(\frac{R_{lvg}}{100-R_{lvg}})$ when R_{vc} is the p.c. recovery of the valuable mineral in the concentrate and R_{lvg} the p.c. recovery of the less valuable mineral in the gangue.

SUMMARY TABLE I

Ref. No.	Reagents	Materials	S.I.
5,6	1 ppm A 70[φ] pH 8.2 50 ppm calgon 189 ppm NaF (hematite flocculated)	-12μm hematite -20μm orthoclase..	4.5
	1 ppm A 100[φ] 50ppm Calgon 126 ppm NaF (orthoclase flocculated)	"	3.5

[φ]B.T.I. Polyacrylamides. Orthoclase fraction contained less than 10 pct. sometimes 2 pct. Fe_2O_3. But hematite fractions were only 70-80 pct. pure.

Ref. No.	Reagents	Materials	S.I.
7	B.T.I. polyacrylamides Sodium tri-polyphosphate 10^{-4}M. Appropriate concentrations	Submicron particles	
		Calcite-Rutile	18.0
		Calcite-Quartz	70.0
		Alumina-Quartz	48.0
		[φ]Alumina-Calcite	8.0

([φ]Alumina sediment contaminated with calcite, but calcite supernatant is purer)

Ref. No.	Reagents	Materials	S.I.
8,9	120 ppm polystrene sulfonate pH 7.8	-20μm hematite and quartz	
		First floc	3.4
		One cleaning	4.5
	100 ppm Starch pH 7.8	"	
		First floc ...	4.8
		One cleaning ...	7.5
		Three cleanings ..	11.2 (max)
	500 ppm hydroxy-propyl cellulose xanthate pH 4.5	-20μm chalcopyrite and quartz	7.0
10	Tannic acid 2.4 g/l Antipyrine 4.8 g/l pH 1.6	-15μm particles	
		Rutile-Quartz	8.5
		Rutile-Hematite	6.4

Note - S.I. Values as defined by us were computed or re-calculated from the original data.

S.I. values corresponding to 75 pct., 80 pct., 90 pct., and 95 pct. recovery values are 3.0, 4.0, 10.0 and 19.0 respectively. Separation Index as defined by Somasundaran[8] $[(\frac{R_{vc} + R_{lvg}}{100}) - 1]$ for the above values are 0.5, 0.6, 0.8 and 0.9 respectively.

While Summary Table I shows separability of 'pure' minerals by selective flocculation, an ore body is a much more complex system and the results obtained from 'pure' systems are hardly applicable. For example, Yarar and Kitchener[4] and Read[5] have pointed out that selectivity is impaired if the pure minerals are co-ground prior to selective flocculation.

No information exists regarding the separability of hematite from clay minerals which occur in Indian iron ores. The work covered under this dissertation was undertaken with the following objectives:

1. To study the separability of hematite fines from Kaolinite, Montmorillonite and Illite fines.

2. To study the flocculation behaviour of fines of different sizes in the range 0-20 mμ.

3. To study the role of starch (and its method of preparation) which is recognised as a good flocculant for hematite[5,6,8,9]

4. To study the role of dispersants like Na_2SiO_3 and modifiers like NaF.

5. To study the effect of successive stages of cleaning and flocculation, and lastly,

6. To quantify the results through computations of grade, recovery and Selectivity Index.

CHAPTER II

MATERIALS, METHODS AND EXPERIMENTS

The details of the chemicals and the materials used are mentioned below:

(1) Minerals Pure Fe_2O_3, Pure Kaolinite, Pure Montmorillonite, Pure Illite.

(2) Chemicals (I) Flocculants - (i) Commercial Starch

(ii) Starch phosphate

(II) Dispersants - (i) Sodium Silicate (Na_2SiO_3)

(ii) Sodium pyrophosphate ($Na_4P_2O_7$)

(III) Modifiers (i) Sodium Fluoride (NaF)

(ii) Sodium Florosilicate (Na_2SiF_6)

(IV) Source of Ca^{++} - $CaCl_2$

(V) pH controller HCl, NaOH

Pure Kaolinite, Montmorillonite, Illite were supplied by Industrial Minerals and Chemical Co. Pvt. Ltd., Bombay.

Size Fractionation of Pure Mineral Particles

In order to study the effect of size of different pure minerals on their flocculation behaviour, minerals of different size fractions were prepared. The pure minerals were wet (distilled water) ground in ceramic ball mills using ceramic balls to avoid iron contamination of pure minerals. The slurry

thus obtained from the ball mill was stirred in a beaker for some time and then it was poured into a bucket partly filled with distilled water, so that the total height of top surface of pulp from the tap was 23.5 ~~sec~~. The amount of slurry used were so calculated that the pulp density of the material in the bucket was approximately 1 pct. These particles were allowed to settle freely in the bucket. The particles of different size fractions were separated by allowing them to settle for different period of time. The settling time for different size fraction of minerals were calculated by using Stokes equation.

$$\text{Stokes equation} = V_t = \frac{1}{18}\ \frac{d^2 \cdot g}{\mu}\ (\rho_s - \rho_o)$$

where V_t = terminal velocity

d = dia. of particle

g = gravity

μ = coefficient of viscosity of fluid

ρ_s = specific gravity of solid particle

ρ_o = specific gravity of fluid (distilled water)

$$\text{Settling time} = \frac{S}{V_t}\ \text{secs}$$

where S = height of settling (23.5 cm)

V_t = terminal velocity

The settling time for the different size fraction of Hematite, Kaolinite, Montmorillonite and illite are given in Table 1 (appendix). The samples were tested under microscope and size range was confirmed qualitatively.

Different - Methods for Preparation of Starch Solution

From the literature survey it was found that there are different methods for preparation of starch solution. Out of those methods some of the important methods were used for preparation of starch solution.

(I) Causticising Method: 0.6 gm of starch was taken in a 500 c.c. beaker and the suspension was prepared by adding 5 c.c. of distilled water. The agglomerates were broken down by a glass rod. Then 5 c.c. of approximately 1 (N) NaOH was added drop by drop till a clear thick gel was formed. Suspension was stirred with glass rod while adding NaOH. Then 200 c.c. of distilled water was added and the suspension was stirred for 30 minutes at 1000 R.P.M. Then the solution was transferred to a measuring flask and the volume was made upto 250 c.c. The pH of this starch solution was 11. So by addition of 10 pct. HCl acid the pH of the solution was brought to 7.25.

(II) Homogenising Method: 0.5 gm of commercial starch was taken in a beaker and small amount of water was added to it. Then with small glass rod, granules of starch were broken and this was continued until a thick pulp of starch was prepared. Then its volume was made upto 200 c.c. and the beaker was heated in a oil bath, controlling the temperature of the bath at 95°C for 20 minutes. During that time continuous stirring was done at nearly 1000 R.P.M. After then the beaker was taken out from the oil bath and the starch solution was taken in volumetric flask and its volume was made upto 250 c.c. The pH of this starch solution was 7.25.

(III) Causticising/Homogenising Method: 0.5 gm of commercial starch was taken in a beaker and with drop by drop addition of water and 0.75 (N) NaOH solution a thick gel was prepared. During that period, stirring was done with the help of a glass rod. After gel preparation, its volume was made upto 200 c.c. with the addition of water. Then the beaker was put under mechanical stirrer and stirring was done for 30 minutes at 1100 R.P.M. Then the volume of the starch solution was made upto 250 c.c. and its pH was adjusted to 7.2 by adding NaOH solution. Then the whole solution was put into a blender and blending was done continuously for 15 minutes at 16,000 R.P.M.

Due to the blending, temperature of starch solution increased to 64°C. Then the starch solution was kept in 250 c.c. volumetric flask. Causticized-Homogenised method some time gave bad reproducibility, and was time - consuming. So this was replaced by a better method i.e. modified causticized-homogenised method.

(IV) Modified Causticized Homogenised Method (MCH): 0.5 gm of commercial starch was taken in a 500 c.c. beaker and to it was added 3 c.c. of distilled water. The agglomorates were broken down by a glass rod. Then 3 c.c. of 0.5 (N) NaOH was added and the suspension was stirred for 1 minute by the glass rod. 0.5 c.c. of 0.5 (N) NaOH was again added and a thick gel was formed by stirring with glass rod for 1 minute and then stirring was stopped and gel was kept for 6 minutes. After this 1 c.c. of distilled water was added and the gel was mixed with glass rod. Water was slowly added with mild agitation with the glass rod and the volume was increased to 300 c.c. This operation was completed in two minutes (total 10 minutes) the starch solution was then homogenised in a homogeniser for 5 minutes at 16,000 R.P.M. Then solution was transferred to a 500 c.c. measuring flask and volume was made upto 500 c.c. The pH of this starch solution was 11.

(V) Starch Phosphate Solution: The preparation of starch phosphate from starch has been described in detail by Baldwa[11].

Out of the different categories of starch phosphate prepared, The starch phosphate containing 3.4 pct. P was used for our flocculation experiments.

0.5 gm of starch phosphate was taken in a 500 c.c. beaker and few drops of water were added to it and the granules of starch were broken by a small glass rod until a homogeneous thin slurry was prepared. Then the whole solution was heated on a heater for 10 minutes. The temperature of solution was raised upto 80°C. Thus we got a clear solution. Then after cooling the starch solution it was put under stirrer for 15 minutes at 1000 R.P.M. After stirring, the pH of this starch solution was measured. This came around 7.5; so by adding 10 pct. HCl solution, the pH of starch solution was brought to 7.3. Then the starch solution was poured in a 250 c.c. volumetric flask and small amount of water was added to make up for the evaporational losses (which occured during heating).

The solution of Na_2SiO_3, $Na_4P_2O_7$, NaF and Na_2SiF_6 were made by dissolving a definite amount of required chemical in 200 c.c. of distilled water. Then the solution was stirred with glass rod. Some heating was also done to dissolve the chemicals in water. Then the solution was brought to room temperature and filtered to remove undissolved material ~~lfet~~ left (if any) and the volume of filtered solution was made upto 250 c.c. and poured into volumetric flask. Thus the total weight dissolved in water

was calculated by subtracting wt. of filtered material from original wt. of chemical. From this, the stock concentration of above solution was calculated.

Flocculation Experiments

Initial flocculation experiments were done in a small settling column (cylindrical jar) with one sampling port at 1/3rd distance from the base. The dimensions of the small jar was 3 cm dia, 16.5 cm height (total). Height of the pulp (100 c.c.) in cylinder was 11.5 cms, and sampling port height from the base was kept at 3.5 cms.

(i) Flocculation of Pure Hematite and Pure Montmorillonite (+ 5µ to - 20µ) with causticized starch as variable at 100 and 400 PPM Na_2SiO_3

The required pulp was taken in a 100 c.c. measuring cylinder and poured into the small cylinder. Then required amount of ~~of and poured into the small cylinder. Then required amount of~~ sodium-silicate was added in the pulp and the cylinder was shaken for 1 minute for proper mixing of Na_2SiO_3. Then required amount of starch solution was added and again the small cylinder was shaken mildly for 1 minute and the cylinder was kept still 3 minutes, time was allowed for settling of floc. Then the port was opened and 70 c.c. of pulp was taken in a aluminium bowl and bottom 30 c.c. was taken in another Al - bowl and dried and their weights were taken. From this, pct. flocculated material

was calculated. For each series, one experiment was done without adding starch, so that we can know the pct. of freely settled material. These experiments were carried out for both hematite and montmorillonite at 100 PPM and 400 PPM of Na_2SiO_3 and at different starch concentrations. The data are given in Tables 2,3,4,5 and data are plotted in Figs. 2,3.

(ii) Flocculation of Pure Hematite (-20μ to +5μ) with causticised starch and homogenised starch. (Both Aged and nonaged) with 100 PPM of Na_2SiO_3

Here the procedure was same as above, only the settling time was reduced to 1 minute and for knowing the effect of aging on flocculation behaviour, the freshly prepared solution was kept at room temperature for 24 hours and then used. The settling time was reduced so that the material settled at zero starch concentration was lowered and it enabled us to see the effect of flocculations more clearly. The data are given in Table 6,7,8,9 and plotted in Figs. 4,5.

Similar experiments were done with Pure Hematite (+ 5μ to - 20μ) with causticised-homogenised starch solution-both aged and nonaged. The settling time was 1 minute while 100 PPM Na_2SiO_3 was used in all experiments. The data are given in Table 10,11, and results plotted in fig. 6. Similar experiments were done with pure hematite (+ 5μ to - 20μ) and pure montomorillonite (+ 5 to - 20μ) using starch phosphate

solution both aged and nonaged at 100 PPM of Na_2SiO_3 concentration and 1 minute of settling time. The results are given Table 12,13,14 and results plotted in fig. 7.

The experiments done with starch phosphate after some time did not the give the same result. This may be due to fact that starch-phosphate was unstable and so with the lapse of time, the phosphoryl group may diffuse out of starch-phosphate lattice and again form Di-sodium hydrogen phosphate (which acts as dispersant).

Similar experiments were done with modified causticized homogenised starch and pure hematite to determine the effect of particle size, pH, starch concentration, Na_2SiO_3 concentration, Ca^{++} concentration on the flocculation of pure hematite. The particle size range which were studied are 0-2μ, 1-8μ, 2-20μ. The pH of the pulp were adjusted by NaOH solution. $CaCl_2$ solution was added as the source of Ca^{++}. The initial Ca^{++} concentration of pulp was determined and it was found to be very very low. So initial Ca^{++} concentration of pulp may be taken as zero.

The sequence of adding were pulp, then Na_2SiO_3 followed by 1 minute shaking, $CaCl_2$ solution followed by 1 minute shaking and starch solution followed by 1 minute shaking. Then

1 minute settling time was allowed. The results are given in Tables 15 to 28 and plotted in Fig. 8 to 14.

Flocculation Experiment with Synthetic Mixtures ($\simeq$ 50:50) of Pure Minerals (1-8μ)

These experiments were done in the flocculating column, the schematic diagram of which is given in Fig. 1. The details of this apparatus are given below.

The flocculating column is a cylindrical vessel made of glass of 11 cm internal diameter and 24 cm height. Its capacity is slightly more than 2 liters. The distance of the tap from the top of the flocculating column is 19.5 cm. Here 16.56 pct. (256 c.c. out of 1600 of pulp) is taken out from bottom as the 'flocculated' part.

Multi-stage flocculation: One multistage flocculation experiment was done with synthetic mixture ($\simeq$50:50) of pure hematite (1-8μ) and pure kaolinite (1-8μ) with modified causticised homogenised starch solution. No Na_2SiO_3 or NaF was used. The pH of pulp was 7.3 and in all stages concentration of starch added was 20 PPM (bulk concentration).

800 c.c. each of pure hematite and kaolinite pulp were taken in a beaker and their pH was measured. Then this synthetic mixture was poured into the flocculating column and stirring was done for 5 minutes to make the pulp homogeneous.

Then the required amount of starch solution was added and stirring was continued for 1 minute at 1000 R.P.M. Then stirring was stopped and after 1 minute unflocculated (NF_1) and flocculated (F_1) parts were taken out in different beaker.

Then the volume of flocculated part (F_1) was made upto 1600 c.c. and it was poured in flocculating column again and stirring was done for 5 minutes and 200 c.c. of sample was withdrawn from column for determination of recovery and grade of 1st stage flocculated part (F_1). Then 200 c.c. of distilled water was added in flocculating column to make the volume of the pulp to 1600 c.c. The same amount of starch solution was again added, and stirring was continued for 1 minute (at 1000 R.P.M.). Then stirring was stopped and after 1 minute flocculated part (F_2) and unflocculated part (NF_2) were taken out in separate buckets.

Then the volume of the 2nd stage flocculated part (F_2) was again made to 1600 c.c. and similar steps were followed as stated earlier.

The volume of unflocculated parts (NF_1, NF_2, NF_3) obtained at 3 different stages was made upto 1605 c.c. separately and from each part 1070 c.c. were taken out for determination of grade and recovery of Hematite and Kaolinite in NF_1, NF_2, NF_3 separately. The ~~devaiving~~ remaining 535 c.c. each of

NF_1, NF_2, NF_3 were mixed properly in a bucket and its flocculation was carried out as mentioned earlier and flocculated and unflocculated parts were taken out separately for determination of grade and recovery. The method of analysis of flocculated and unflocculated parts are given below. The results are given in Table 29 and results plotted in Fig. 15.

Analysis by HCl-dissolution Method: For analysis of flocculated and nonflocculated portion 1 gm of the dried sample to be analysed was taken in a 250 c.c. beaker. Then 200 c.c. of 35 pct. HCl solution was added to this beaker and then whole solution was heated for 10 minutes on electric heater, so that all Fe_2O_3 went into solution while kaolinite, illite and montmorillonite did not go into solution. Then the beaker with solution was cooled to room temperature and the solution was filtered through a previously weighed filter paper. After filtration and repeated washing of filter paper, the filter paper was dried and its weight was taken. The increase in the wt. of filter paper gives the wt. of undissolved mineral i.e. montmorillonite or illite or kaolinite. So by subtracting this wt. from 1 gm, we get the amount of the mineral dissolved (i.e. wt. of Fe_2O_3 in sample).

The results of multistage flocculation is given in table 29.

<u>Single Stage flocculation using modified causticised homogenised starch solution</u>:

Single stage flocculation experiments were carried out with synthetic mixture (50:50) of Hematite-Kaolinite, Hematite-Montmorillonite, Hematite-iilite all of 1-8m size. Single stage flocculation was done to determine the optimum dosage of starch, NaF_2 Na_2SiO_3, $Na_4P_2O_7$, Na_2SiF_6 and optimum pH. The sequence of experiments was as follows: at first, optimum dosage of starch was found, the optimum pH at this optimum starch concentration was found. Then optimum concentration of Na_2SiO_3 was found using optimum starch concentration and optimum pH. Then optimum dosage of NaF was found out using optimum value of other variables using optimum value of other variables. One set of experiment was also done after replacing NaF by Na_2SiF_6. In all experiments, pulp density was kept to approximately 1 pct. The results are given in Table 30 to 35 and plotted in fig. 16 to 20.

800 c.c. of pure hematite and pure kaolinite pulp each were taken in a beaker. Then pH was adjusted if required. Then pulp was poured into the flocculating column and vigorous stirring was done to homogenise the pulp. The fixed amount of Na-silicate solution or $Na_4P_2O_7$ solution was added (if required), and stirring was done for 7 minutes. Then fixed concentration of NaF or Na_2SiF_6 were added (if required) and

stirring was carried out for 1 minute. Then fixed concentration of starch solution was added and stirring was done at 1000 R.P.M. for 1 minute. Stirring was stopped and flocs were allowed to settle for 1 minute. These unflocculated and flocculated parts were taken out separately, filtered and dried and their weights were taken. Then from both flocculated and unflocculated parts 1 gm of samples were taken out for analysis.

Similar experiments were done with hematite-montmorillonite and hematite-illite synthetic mixture.

The results are given in Table 36 to 43, and plotes in Fig. 21 to 28. In this series ~~to~~ of experiments, after the 1st stage flocculation, the flocculated, part was again poured into the flocculating column containing distilled water (total volume = 1600 cc i.e. volume of floc + volume of distilled water). Then 2 minutes mild stirring (700 R.P.M.) was done. After stirring, the material was allowed to settle for 1 minute then floc and nonfloc parts were taken out and analysed.

In all experiments, commercial starch solution (made by different methods) were used, unless otherwise specified.

Pulp density in all experiment was maintained at approximately 1 pct.

CHAPTER III

EXPERIMENTAL RESULTS

In the previous chapter, various experimental works were reported. The results are given in Tables 1-43 in the appendix and also reported in Figs. 2-28.

Starch flocculates hematite appreciably but montmorillonite feebly (Fig. 3). Method of preparation of starch solution was found to be important. Mere homogenisation gave poor results (Fig. 4). For causticized starch, 40 ppm concentration was optimal (Figs. 2,5) and ageing of solution gave inferior results. Starch phosphate was found to be a strong flocculant but ageing gave inferior and less reproducible results (Fig. 7). Modified causticising Homogenizing (MCH) method for preparation of starch solutions gave best reproducible results (Fig. 8).

0-2 mμ hematite particles were less flocculable than 5-20 mμ particles particularly in presence of sodium silicate (Fig. 8,9). Subsequent experiments were done with 1-8 mμ particles, for which 20 ppm concentration of starch was optimal, and the effects of Ca^{++} and sodium silicate were small (Figs. 11-14).

Single ~~Three~~-stage flocculation experiments (1-8 mμ) were done on the following mineral pairs: Hematite-kaolinite (Figs. 16-20), Hematite-Montmorillonite (Figs. 21-24), Hematite-Illite (Figs. 25-28). Better results were obtained with starch concentration around 40 ppm in presence of 100 ppm sodium silicate, 50 ppm sodium fluoride and pH 9.5. Use of sodium pyrophosphate and sodium silico-fluoride gave inferior results. The best result obtained so far was for 1-8 mμ Hematite-Kaolinite System, (Fig. 17) where both grade and recovery of hematite were ~~was~~ 78 pct. and Selectivity Index was 3.58.

Summary Table II provides details regarding the Tables, Figures and pertinent observations.

SUMMARY TABLE II - EXPERIMENTAL RESULTS

[Abbreviations: Hematite (H), Kaolinite (K), Montmorillonite (M), Illite (I), Starch (ST), Causticized (C), Homogenized (HM), Causticized-Homogenized (CH), Modified Causticizing-Homogenizing (MCH), Starch Phosphate (STP), Sodium Silicate (SS), Sodium Pyrophosphate (SP), Sodium Fluoride (SF), Sodium Silicofluoride (SSF)]

Fig. No.	Corresponding Tables	Materials for flocculation Experiments	Conclusions
1	x	Apparatus	
2	2-3	H 5-20 mμ ST(C) 0-200 ppm SS 100 and 400 ppm	Optimum 40 ppm ST 100 ppm SS better
3	4-5	M 5-20 mμ	Very little flocculation
4	6-7	ST (HM) H 5-20 mμ	Little flocculation even for H
5	8-9	H 5-20 mμ ST (C)	Optimum 40 ppm ST(C) Non-aging better
6	10-11	H 5-20 mμ ST (CH)	Optimum 2o ppm ST (CH) Not much difference between ageing and non-ageing
7	12-14	H 5-20 mμ STP	Optimum STP 10 ppm Non-ageing better. Very little flocculation for M
8	15-16	H 0-2 mμ ST (MCH) All subsequent expts were with MCH starch	Optimum 40 ppm ST(MCH) 7.3 pH better than 10.4
9	17-18	H 0-2 mμ	Optimum ST 40 ppm better without SS

10	19-20	H 0-2 mμ Ca^{++} concn. 0-100 ppm	Ca^{++} does not affect the degree of flocculation of H
11	21-22	H 1-8 mμ	Optimum 20 ppm ST pH 10.5 better than 7.3
12	23-24	H 1-8 mμ	Effect of SS little
13	25-26	H 1-8 mμ	Effect of Ca^{++} little
14	27-28	H 2-20 mμ	Optimum 40 ppm ST 7.2 pH better at 100 ppm SS
x	29	Single stage flocculation with H + K 1-8 mμ ST 10, 20 and 40 ppm	Best S.I. (2.2) with 20 ppm ST
15	30	Three stages flocculation ST 20 ppm pH 7.3 No dispersant	Best Selectivity Index (S.I. (2.67) was obtained with 75 pct. grade

SINGLE STAGE FLOCCULATION EXPTS.

16	31	50 : 50 mixture of H/K 1-8 mμ	Optimal grade with 100 ppm SS (72 pct. G, 78 pct. R, S.I. 2.86)
17	32	" "	Optimal grade with 100 ppm SS and 50 PPM SF (78 pct. G, 78 pct. R, S.I. 3.58).
18	33	" "	Optimal grade with 50 ppm SP (70 pct. G, 76 pct. R, S.I. 2.6)
19	34	" "	Optimal grade with 50 ppm SP and 50 ppm SF (76 pct. G, 74 pct. R, S.I. 3.1)

20	35	H and K 1-8 mμ ST 40 ppm pH 10.5 SSF 0-100 ppm	Steady fall in recovery and grade with use of SSF
21	36	H and M 1-8 mμ ST 0-100 ppm pH 7.3 No dispersant starting from this expt. onwards flocs were 'washed'	Optimum ST 40 ppm (65.3 pct. G, 55.8 pct. R S.I. 1.73)
22	37	'' '' pH range 7-10.5	Optimum pH 9.5 (66.8 pct. G, 58.1 pct. R S.I. 1.85)
23	38	'' pH 9.5 ST 40 ppm SS 0-150 ppm	Optimum SS 100 ppm (71.7 G 64.1 R S.I. 2.3)
24	39	'' SS 100 ppm SF 0-100 ppm	Optimum SF 50 ppm (76G 73.7R S.I. 3.12)
25	40	H and I 1-8 mμ pH 7.3 No dispersant	Optimum ST 40 ppm (67G 61.4R S.I. 1.92)
26	41	H and I 1-8 mμ ST 40 ppm pH 7-10.5	Optimum pH 9.5 (68.3G 62.7R S.I. 2.03)
27	42	H and I 1-8 mμ ST 40 ppm pH 9.5 SS 0-150 ppm	Optimum SS 100 ppm (73.7G, 69.3R, S.I. 2.6)
28	43	'' SS 100 ppm SF 0-100 ppm	(Optimum SF 50 ppm 77.6G, 76.0R, S.I. 3.36)

CHAPTER IV

DISCUSSION AND CONCLUSIONS

It has been established that starch helps in the flocculation of hematite, whereas montmorillonite and other clay minerals are not appreciably flocculated.

Gururaj established[12] that kaolinite is the best dispersable mineral of the four studied and hematite the poorest (probably there is a density effect apart from the charge effect). $Na_2P_4O_7$ was found to be slightly better as a dispersant than Na_2SiO_3 only for montmorillonite and illite but not for kaolinite and hematite. The use of dispersants may be general or selective whereas the use of starch as flocculant is specific. Bhagat showed[13] that starch is chemically and irreversibly adsorbed on hematite. He establishe the above through I.R. and micro-calorimetric work. This present work corroporates the effect of starch on hematite as a flocculant pointed out by Read et al[5,6] and Somasundaran et al[8,9].

20-40 ppm starch concentration seems to be optimal. Higher proportion of starch may form more than half a monolayer coating[13]. 100 ppm sodium silicate gives better results than

400 ppm. Higher dosage of dispersant over-disperses hematite and prevents adsorption of starch and causes formation of fluffy or porous flocs which settle very slowly.

Mere homogenisation of starch does not give good results probably becauses the grains are not ruptured, and hence much of the starch remains undissolved. Causticising and homogenising or prolonged stirring at high RPM attended by consequent increase in temperature causes appropriate dissolution and shortening of the chain length of starch molecules. Thus dosage required for optimal flocculation is also reduced.

After flocculation experiments, it was seen that for zero dosage of starch, the dried material was in powdery form whereas for starch dosage of 20 + ppm, the dried material was in the form of small globules, which did not break even during vigorous boiling. Inferior results were obtained if the starch solution was allowed to 'age'; this could have happened on account of some bio-degradation. A similar phenomenon was observed for starch phosphate which otherwise gave pronounced and faster flocculation. For aged solutions and solutions of higher concentrations, much less number of flocs were visible to naked eyes. Under optimal conditions, large number of small flocs were seen.

Since aluminium-containing grains in Indian iron ores were found[1] to be 2 mμ or less in size, flocculation behaviours of 0–2 mμ particles were studied. Very fine particles of hematite could be easily flocculated by starch. However sodium silicate adversely affected flocculation of 0–2 mμ hematite particles* (but not coarser particles). Ca^{++} did not affect flocculation of either fine or coarse hematite particles. For both categories of particles, the optimum dosage of starch seemed to be around 40 ppm. For 0–2 mμ particles of a hematite-clay mixture, the use of dispersants like Na_2SiO_3 remains problematical: Without it clay particles are not adequately dispersed, and with it hematite particles are difficult to flocculate.

Uses of dispersants and depressants are related to crystal structure and charge properties of clay[14]. The basic building units of clay minerals are the sheets formed by linking together Si–O tetrahedra and the two dimensional arrays of ~~cotahedra~~ octahedra formed by the six fold co-ordination of Al^{3+} or Mg^{+} with oxygen and hydroxyl groups. The Si–O sheets are joined to the octahedral sheets by sharing oxygen atoms. In clays of the montmorillonite and illite type, the repetitive structural unit, to be referred to as a sandwich, consists

* Weight pct. flocculated was low (57 pct. in Fig. 8) and flocs were weak. For coarser particles 5–20 mμ (Fig. 5), 1–8 mμ (Fig. 12), 90 pct. material was flocculated and flocs were stronger.

of two tetrahedral Si-O sheets separated by one octahedral sheet. The 'sandwiches' are held together by alkaline cations (Na^+ or K^+) because some of the Si^{4+} ions in the Si-O tetrahedra are replaced by Al^{3+} thereby giving the sandwich a negative charge. The surface of the clay mineral is formed by breaking the bonds between these cations and the tetrahedral sheet. When placed in water, the alkaline cations move away from the sheets into the solution leaving the clay surface negatively charged. Thus the clays exhibit considerable base-exchange properties and adsorb ammonium ions, etc. Kellogg reported[15] flotability of kaolin from quartz using amines of pH 3. The surface of the clay mineral perpendicular to the sheets is formed by breaking Si-O or Al-O bonds and may bear positive charge[14]. The positive charges in the lateral edges of clay particles are assumed to be responsible for the coating of negatively charged coal by clay eventhough clay may have overall negative charge like coal.[16] A similar coating mechanism of clay over negatively charged hematite particle is possible. Negative as well as positive charges on the same particle in different orientations make the clay particles hetero-coagulate with or coat other mineral particles. The alkali and alkaline earth cations may also provide links alongwith flocculants between clay and other flocculated minerals.

Figs. 15-28 show that selective flocculation of hematite is possible using Na_2SiO_3, NaF apart from starch. While sodium silicate augments charge on clay particles and promotes dispersion, NaF depresses clay particles in terms of adsorption of flocculant[5,6]. Na_2SiF_6 apparently depresses both clay and hematite reducing flocculability of the latter. Fig. 17, Table 32 indicate the best result obtained so far; 78 pct. grade, 78 pct. recovery, Selectivity Index 3.58 for 1-8 mμ Hematite-Kaolinite mixture with 40 ppm starch, 100 ppm sodium silicate and 50 ppm sodium fluoride. Repeated flocculation gave much lower recovery and slightly better grade.

There is scope for further research on selective dispersants, depressants and flocculants since Summary Table I in Chapter I indicates that S.I. values higher than 3.58 are attainable in several mineral pair systems.

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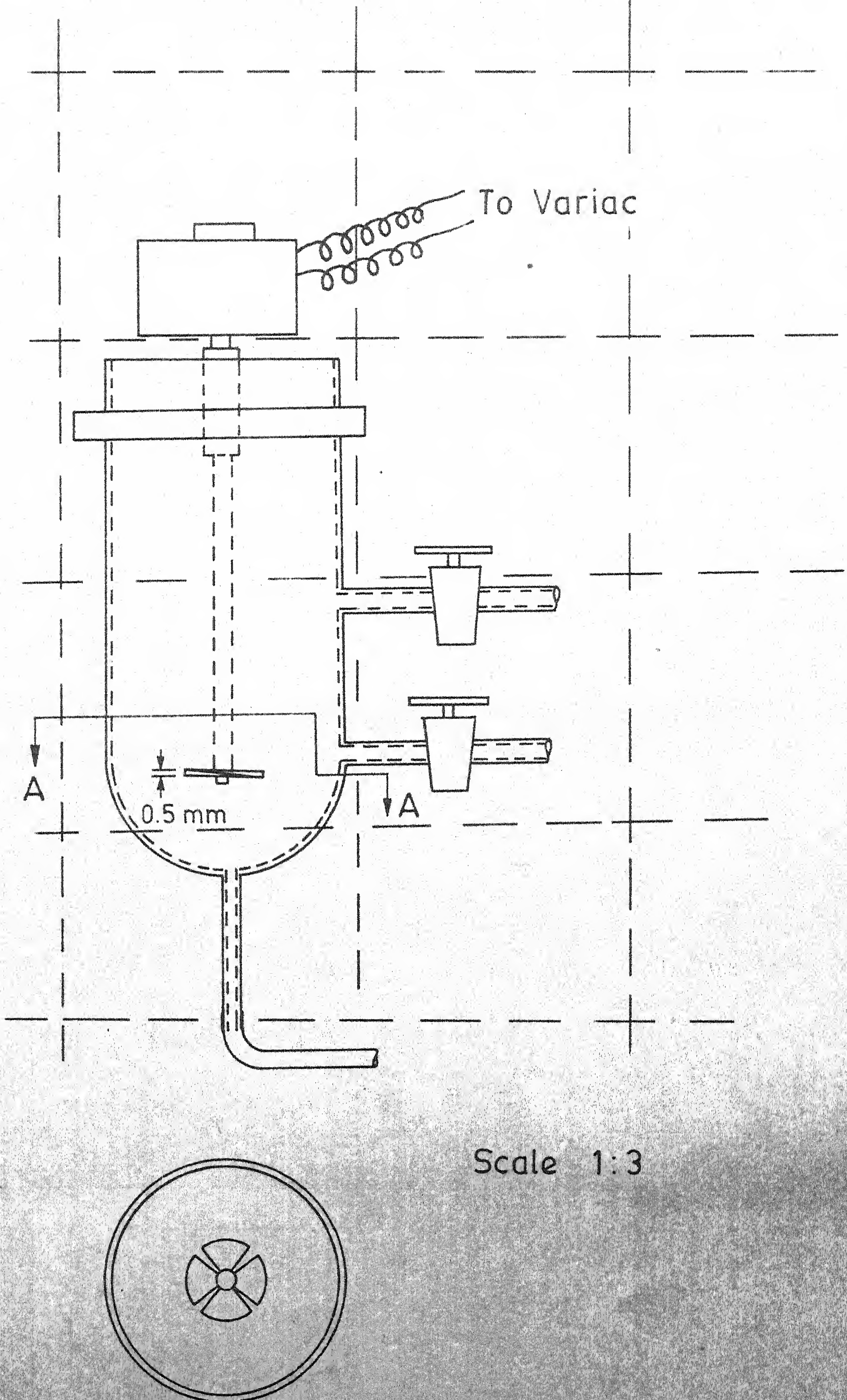


Fig. 1 - Flocculating column.
(Schematic diagram)

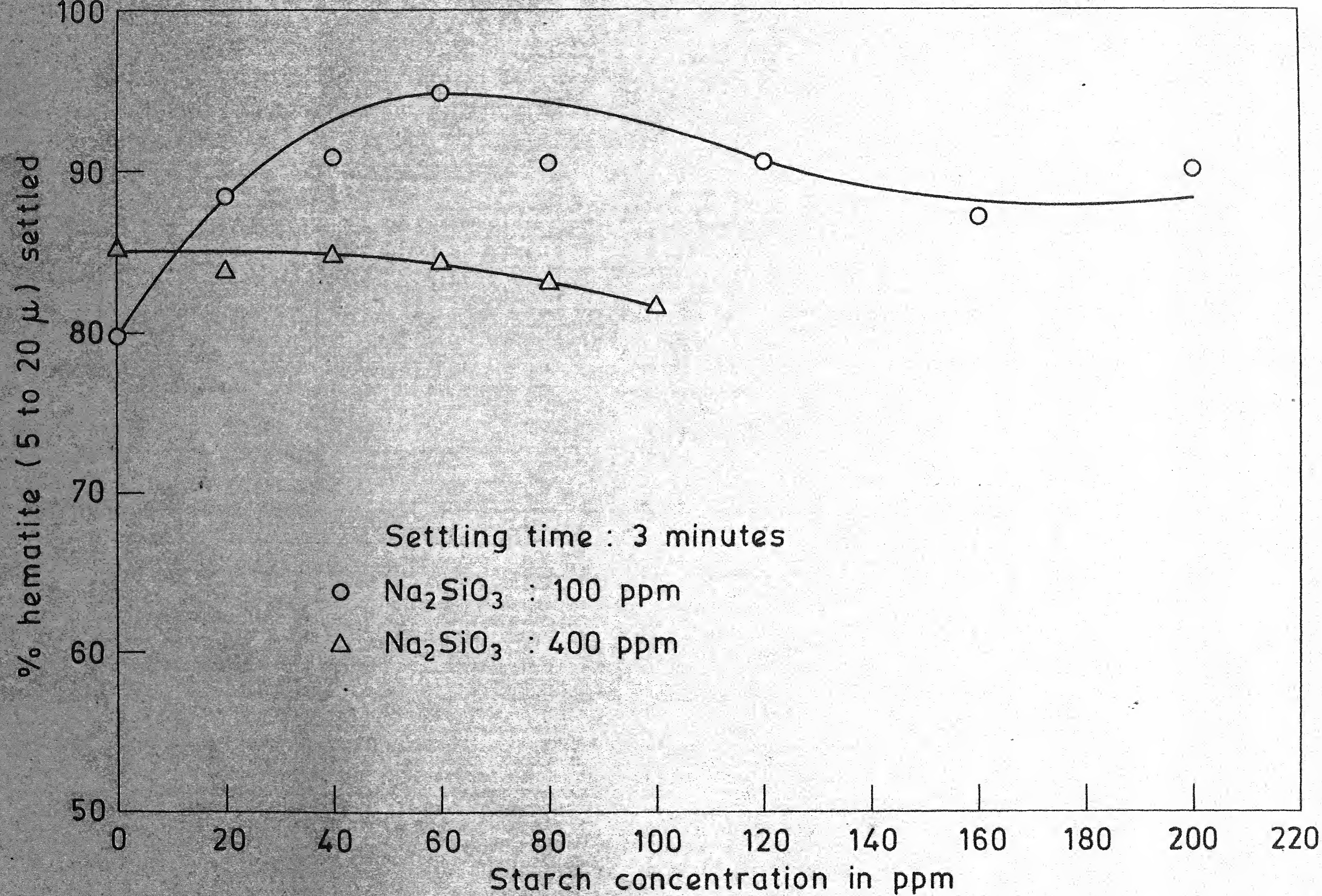


Fig. 2 - Effect of different causticised starch concentration on the flocculation of pure hematite at normal pH. Ref. Table 2 & 3.

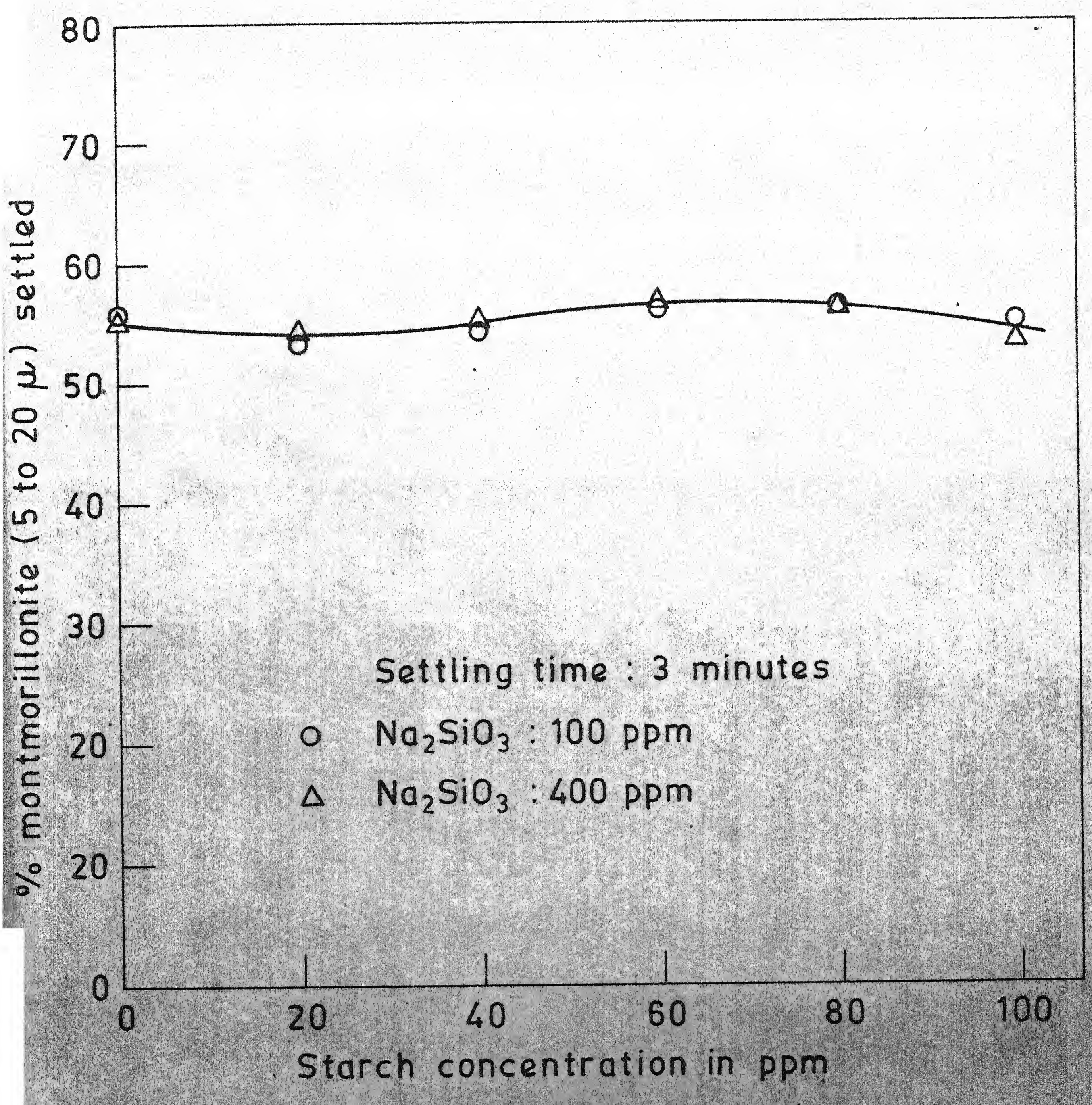


Fig. 3 - Effect of different caustised starch concentration on the flocculation of pure montmorillonite at normal pH.
Ref. Table 4 & 5.

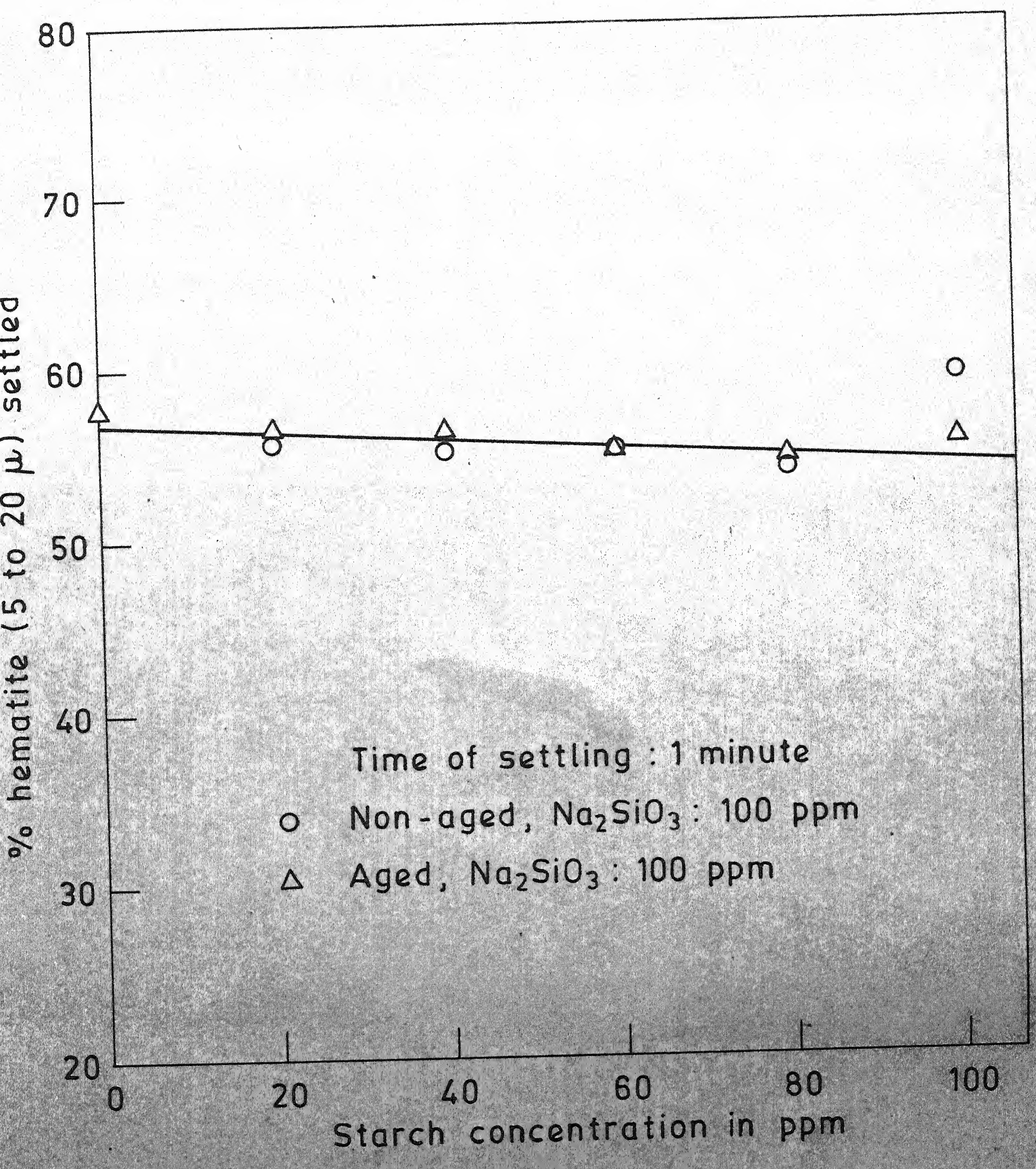


Fig. 4 - Effect of different dosages of homogenised starch on the flocculation of pure hematite at normal pH. Ref. Table 6 & 7.

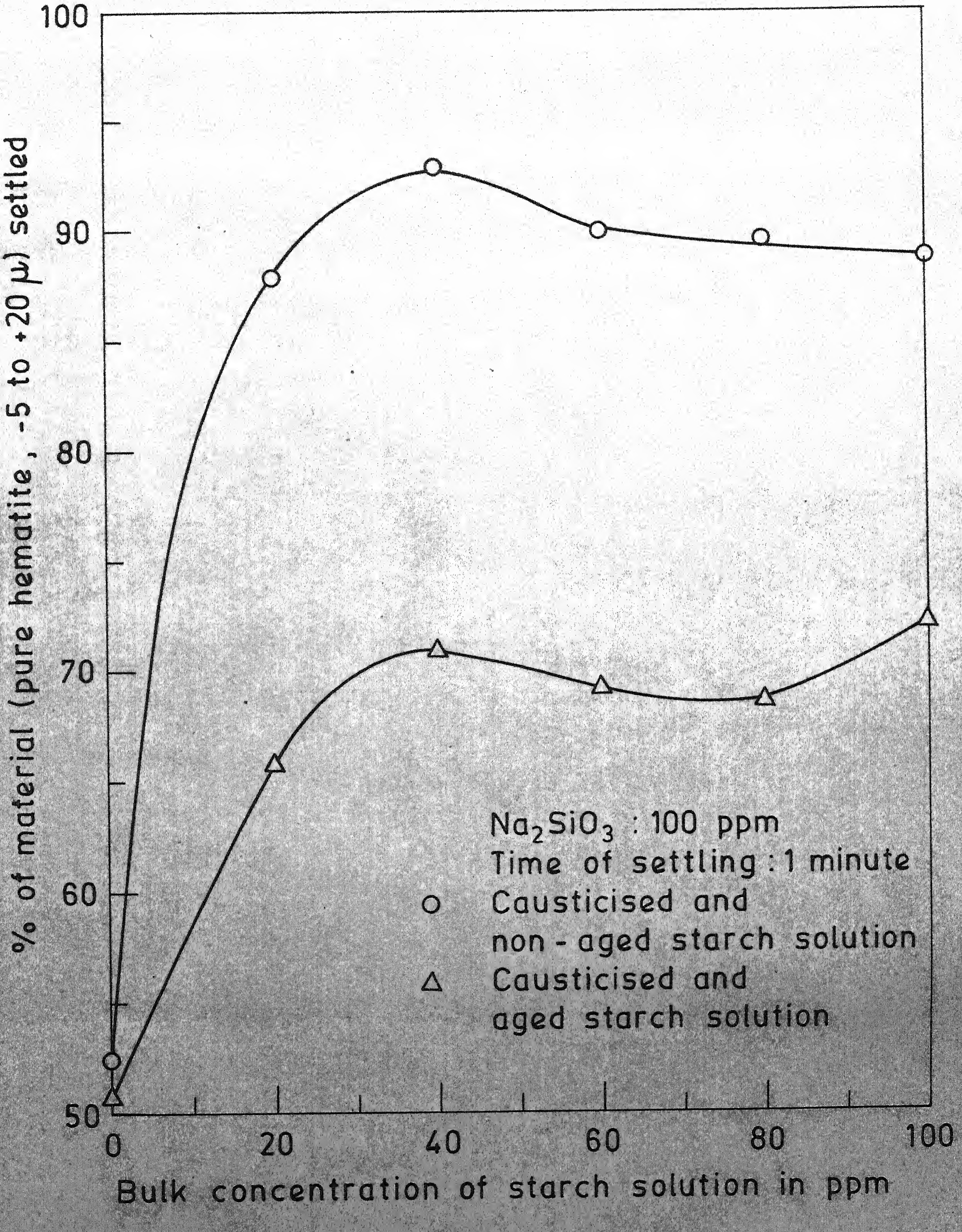


Fig. 5- Effect of starch concentration on the flocculation of pure hematite. Ref. Table 8 & 9.

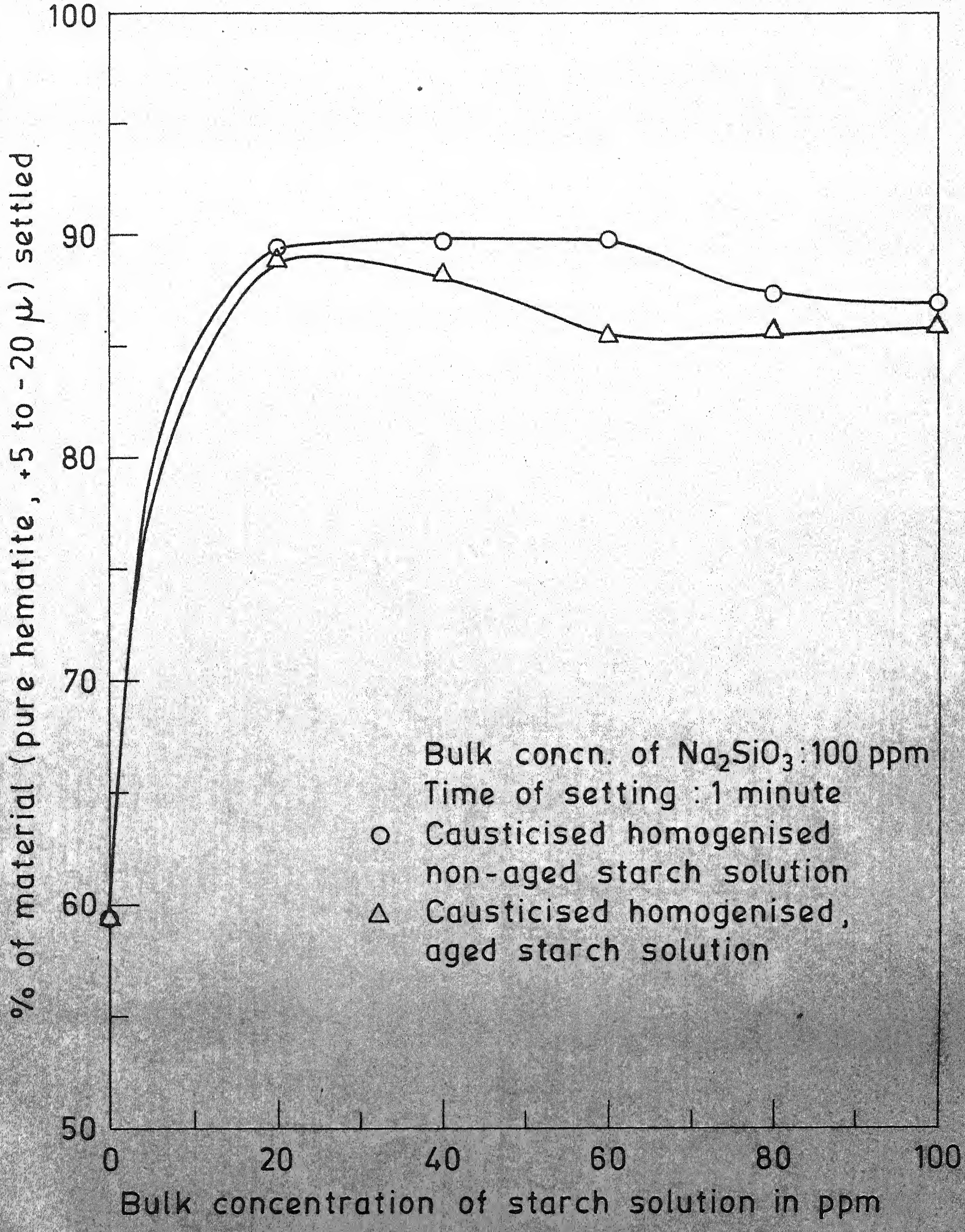


Fig. 6 - Effect of starch concentration on the flocculation of pure hematite. Ref. Table 10 & 11.

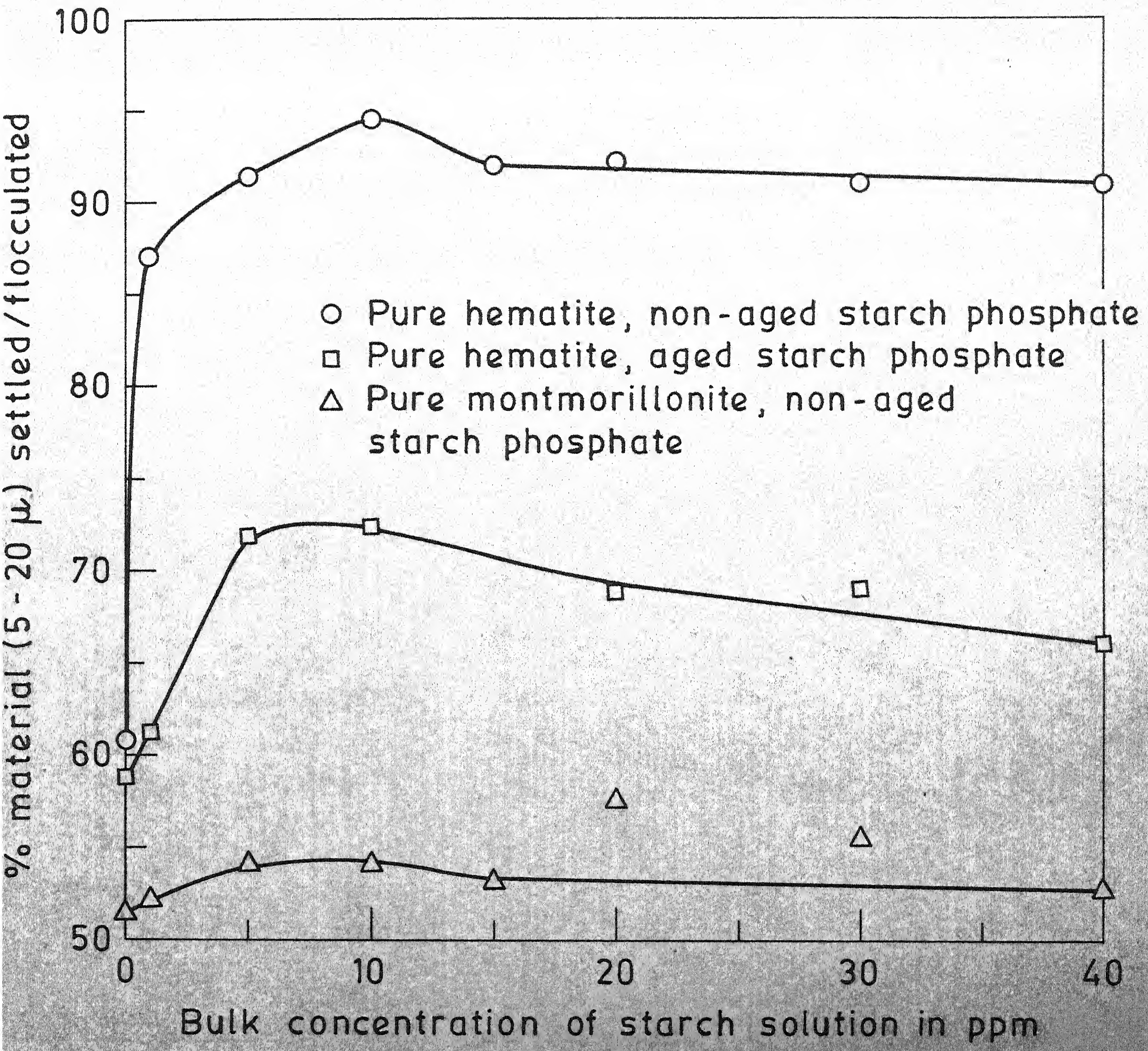
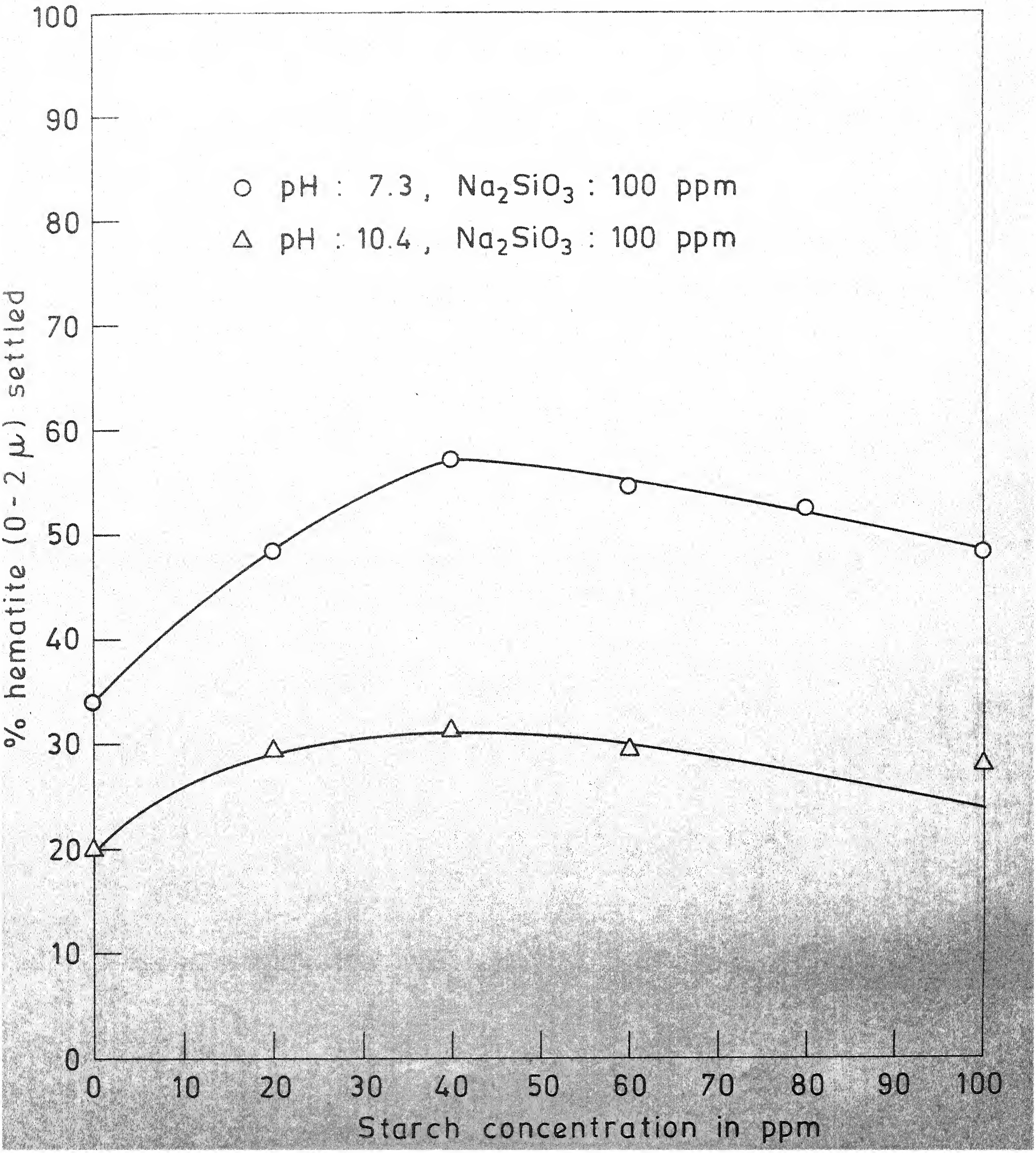


Fig. 7 - Effect of starch phosphate concentration and mode of preparation on flocculation of minerals.
Ref. Table 12, 13 & 14


100
90
80
70
60
50
40
30
20
10
0
○ pH : 7.3 , Na_2SiO_3 : 100 ppm
△ pH : 10.4 , Na_2SiO_3 : 100 ppm
% hematite (0 - 2 μ) settled
0
10
20
30
40
50
60
70
80
90
100
Starch concentration in ppm

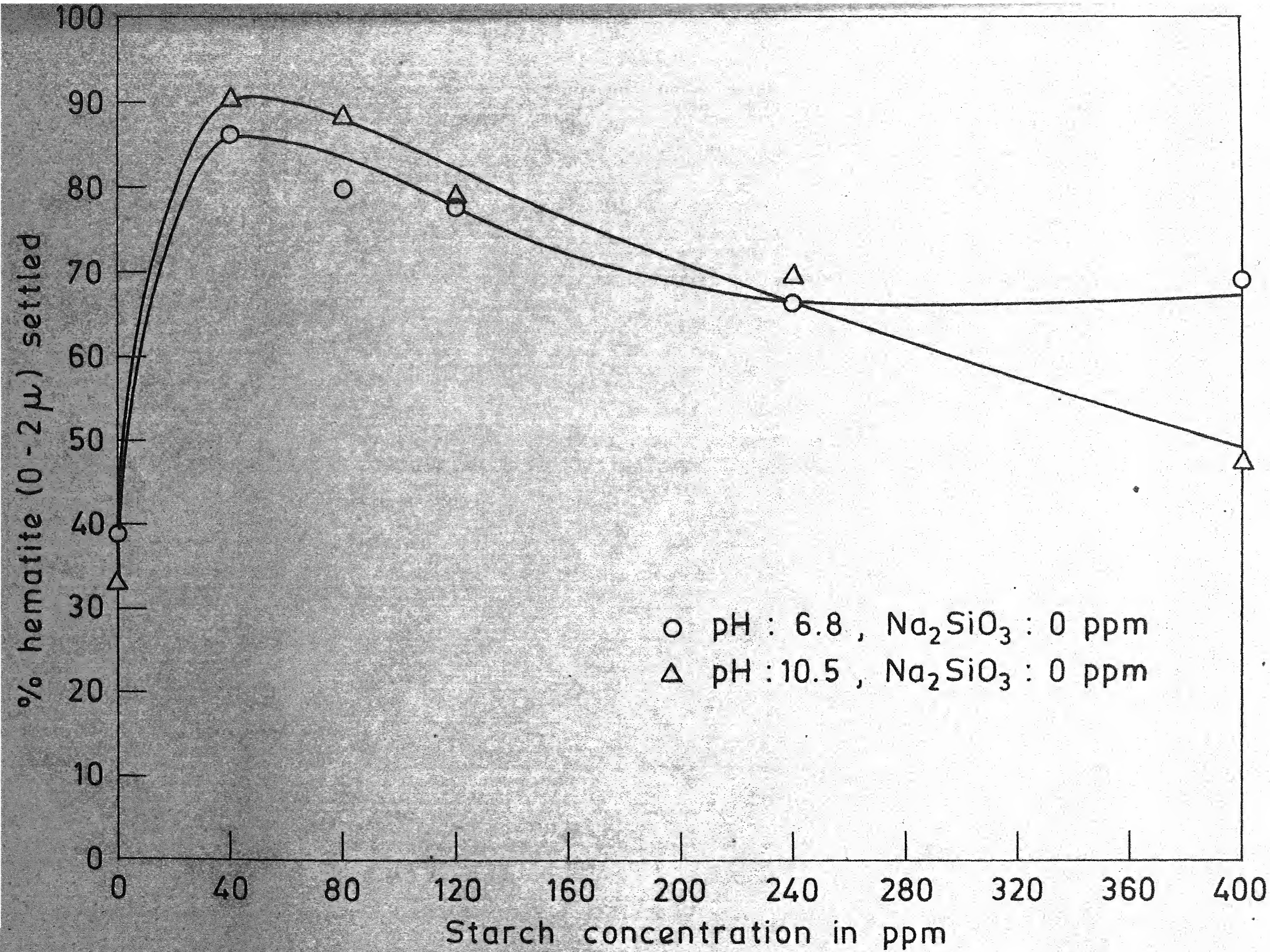


Fig. 9- Effect of starch concentration on flocculation of hematite. (in absence of Na_2SiO_3). Ref. Table 17 & 18

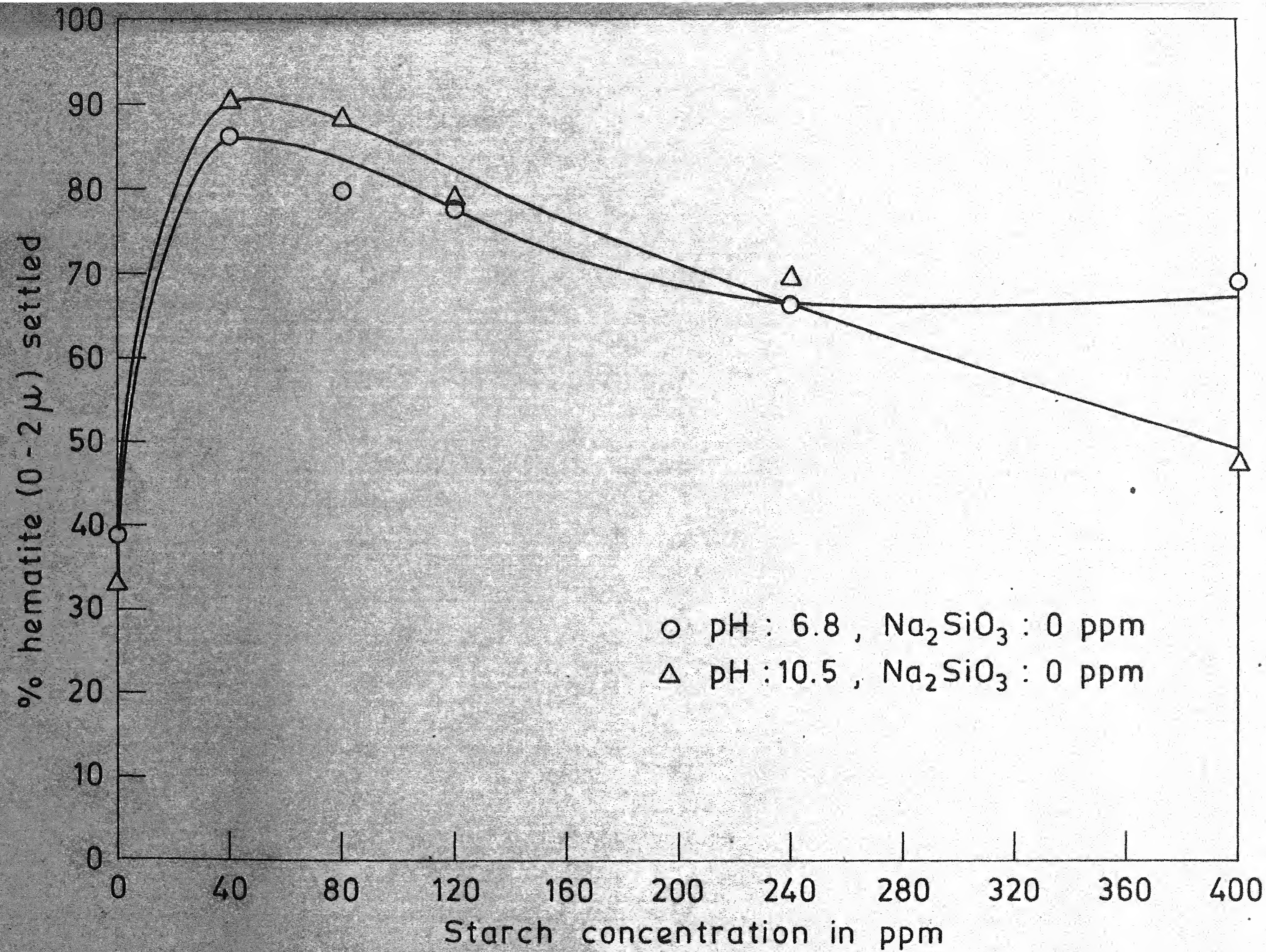


Fig. 9- Effect of starch concentration on flocculation of hematite. (in absence of Na_2SiO_3). Ref. Table 17 & 18

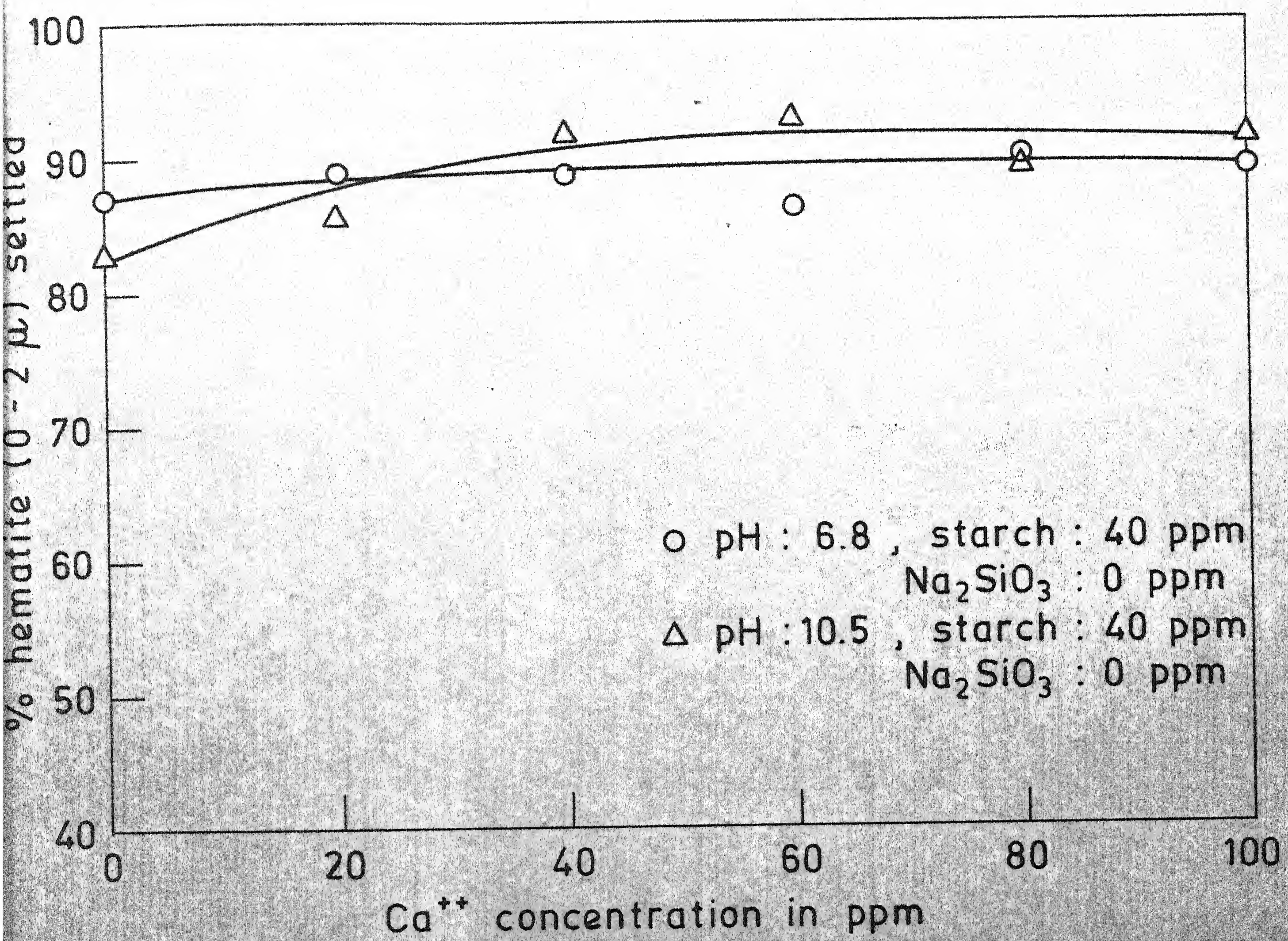


Fig. 10 - Effect of Ca^{++} on the flocculation of pure hematite.
Ref. Table 19 & 20

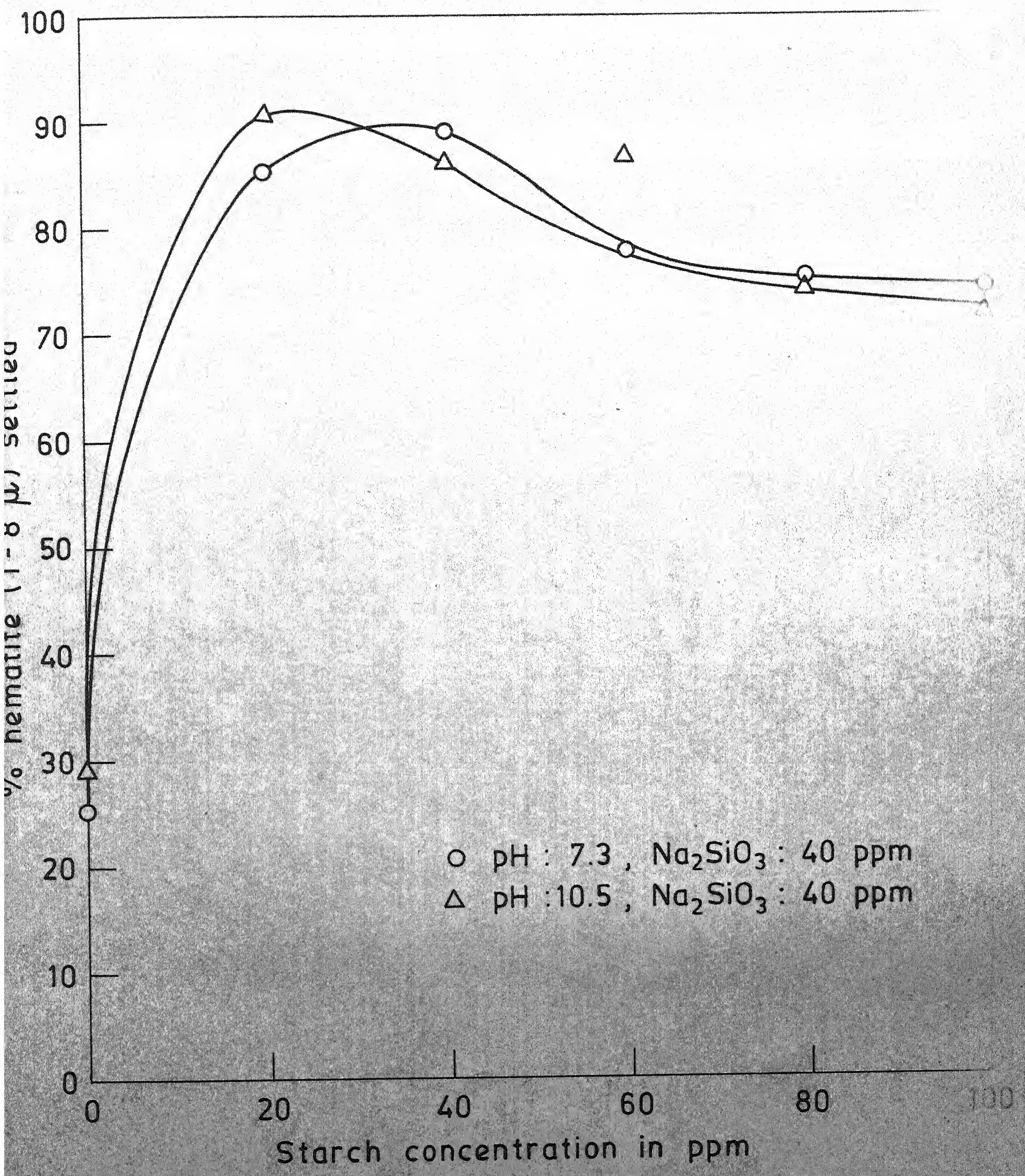


Fig. 11- Effect of starch concentration on flocculation of hematite. Ref. Table 21 & 22

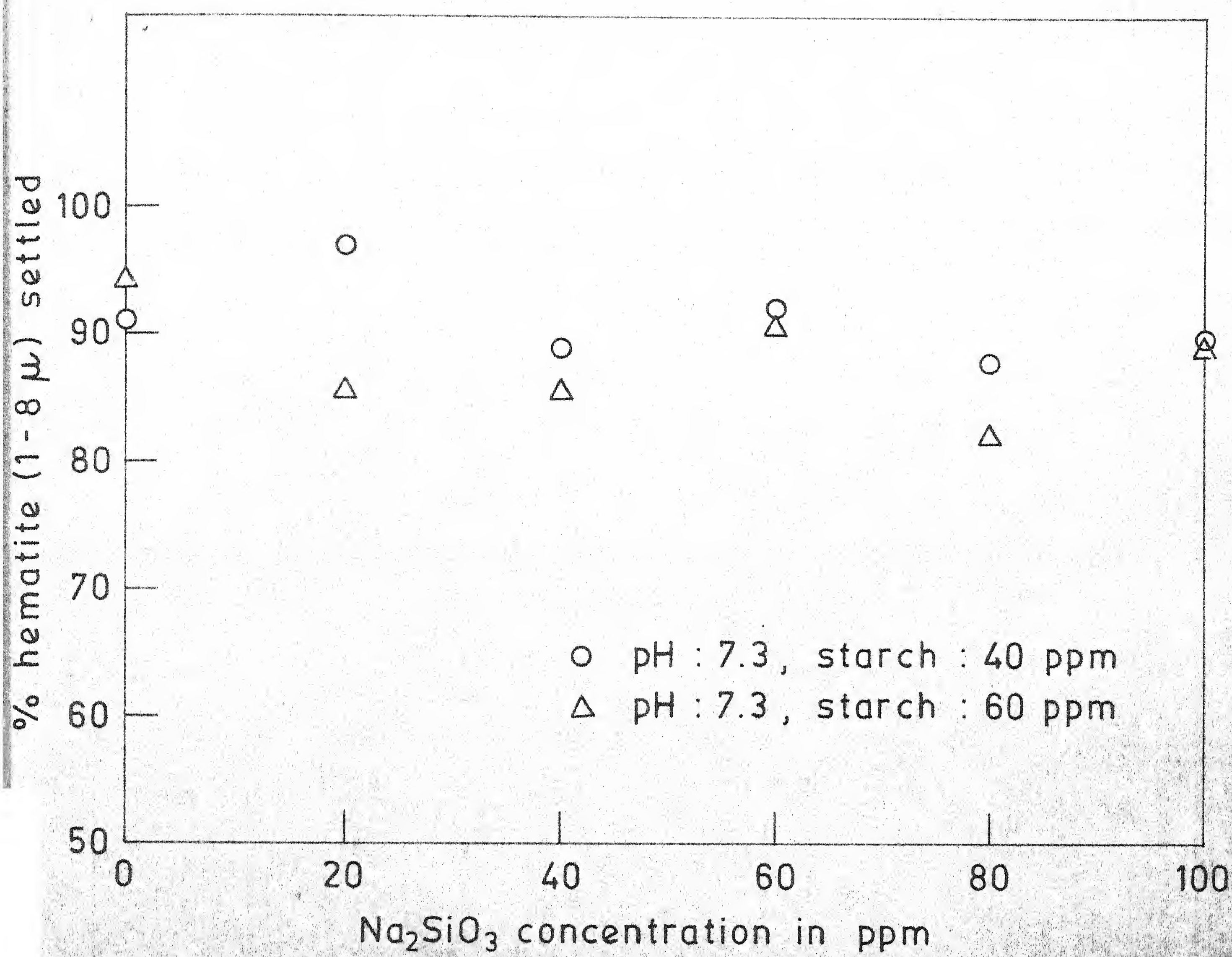


Fig. 12 - Effect of Na_2SiO_3 concentration on flocculation of hematite.
Ref. Table 23 & 24

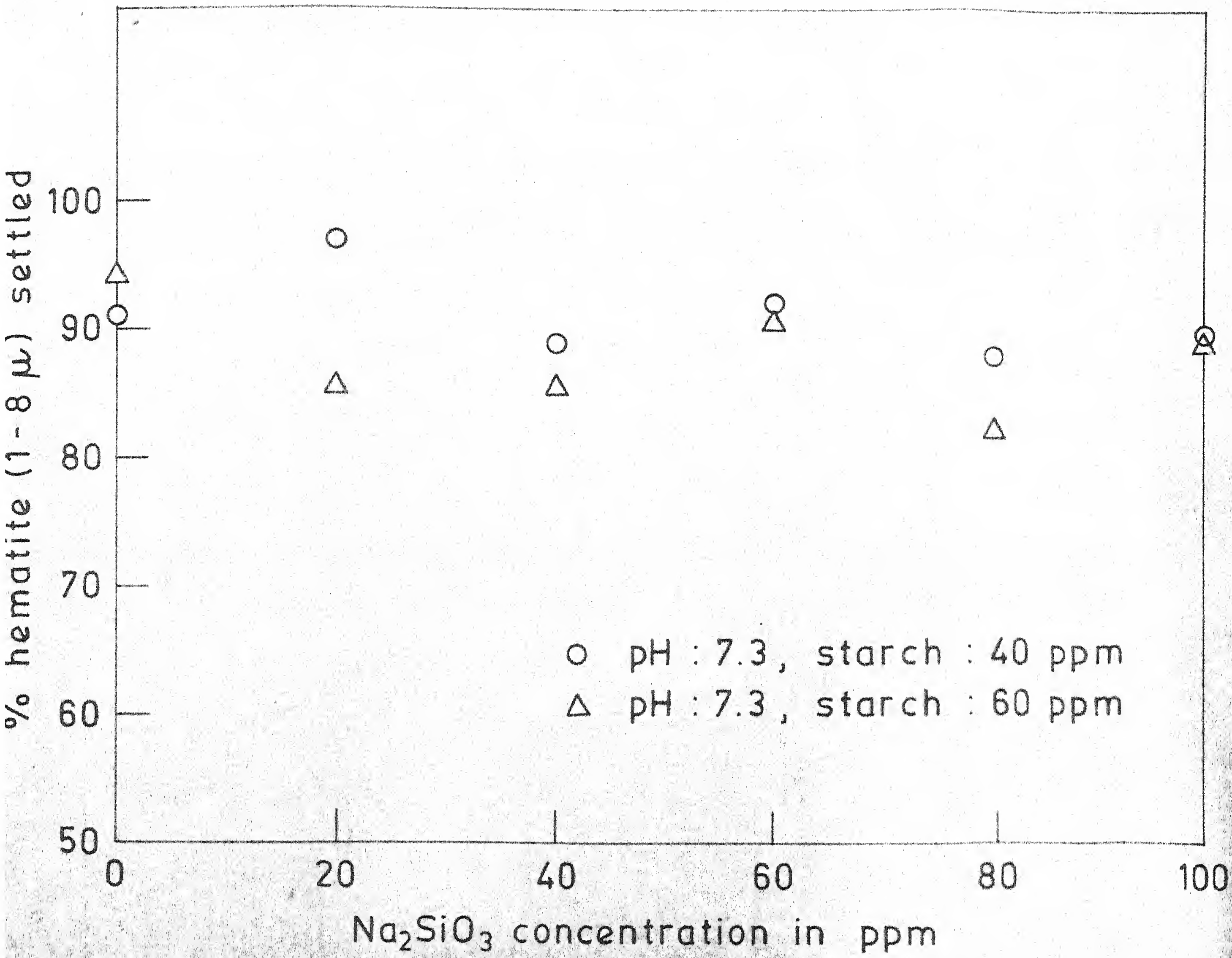


Fig. 12 - Effect of Na_2SiO_3 concentration on flocculation of hematite.
Ref. Table 23 & 24

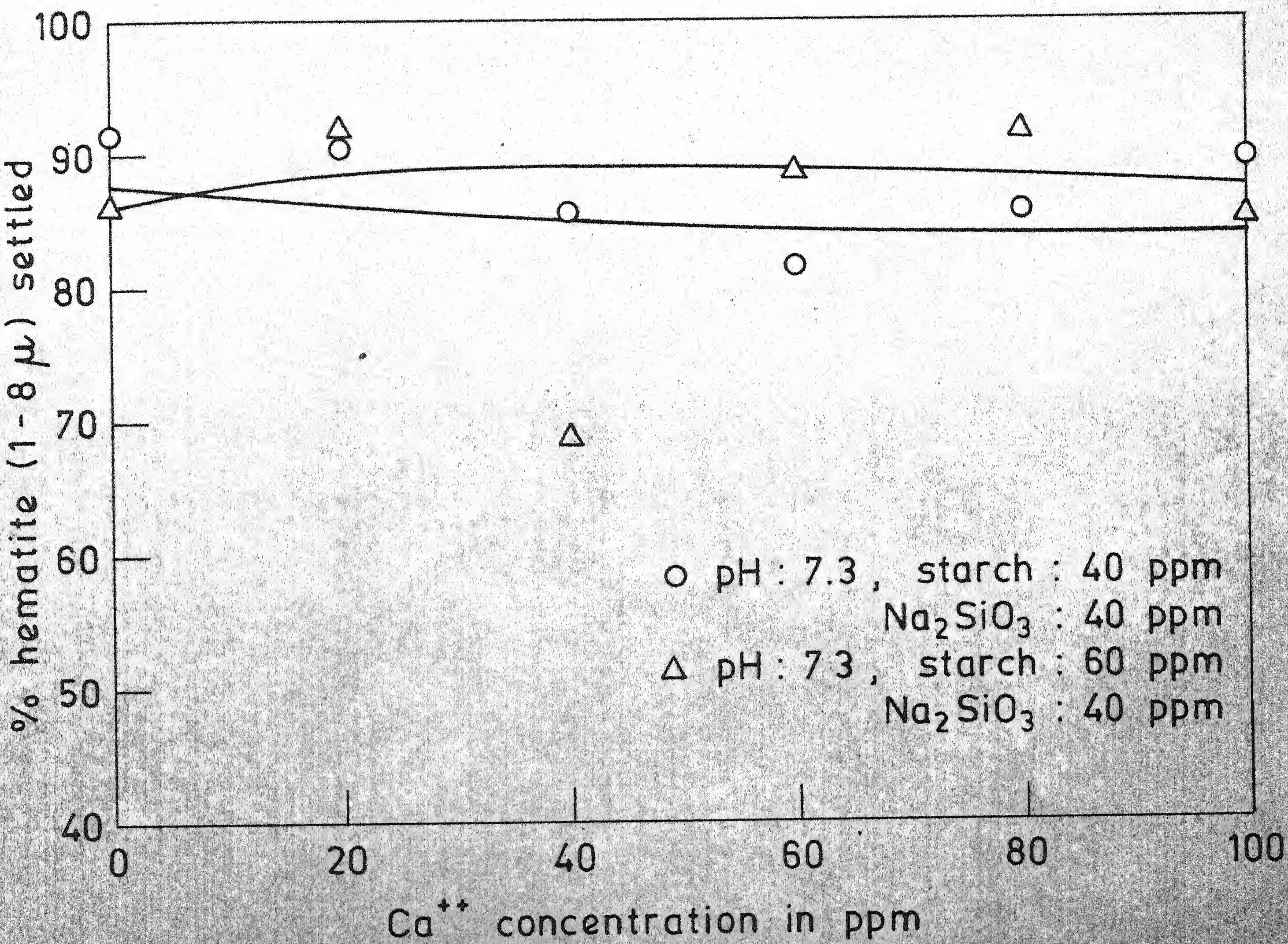


Fig. 13 - Effect of Ca^{++} concentration on the flocculation of hematite.
Ref. Table 25 & 26

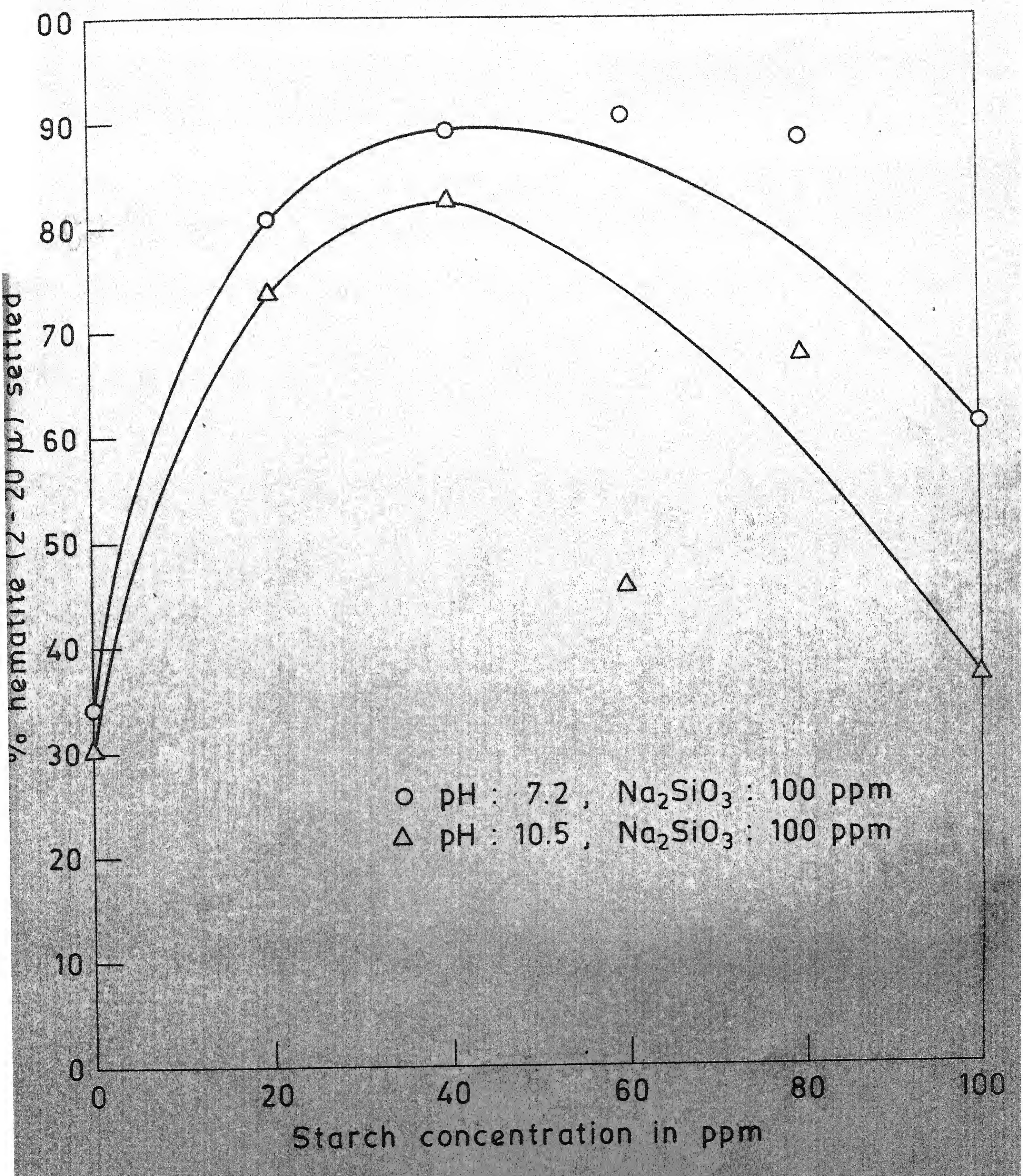


Fig. 14- Effect of starch concentration on flocculation of hematite. Ref. Table 27 & 28

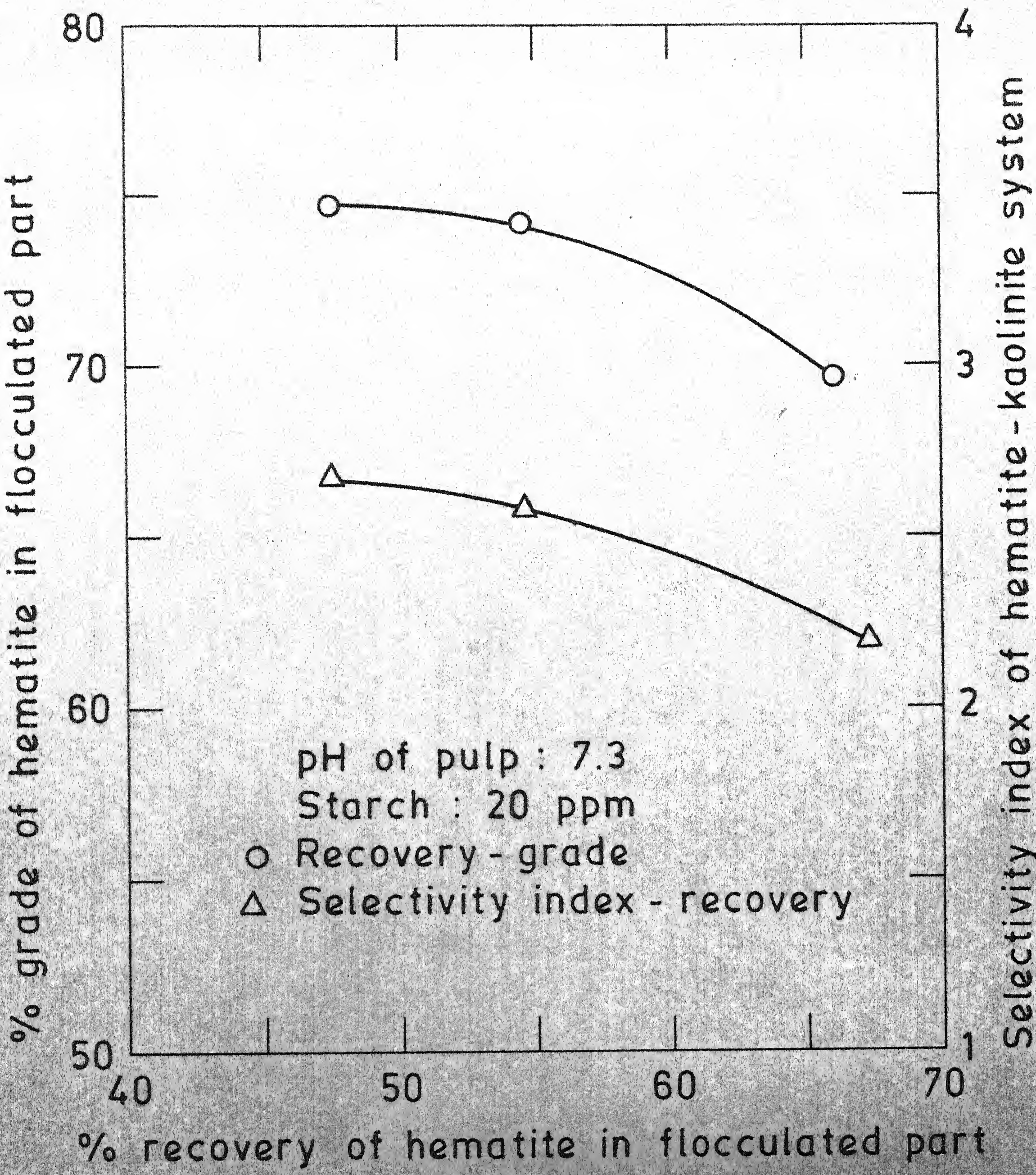


Fig. 15 - Effect of cleaning on the recovery, grade and selectivity index in hematite - kaolinite (≈50 : 50) mixture of 1 - 8 μ particle size. Ref. Table 30.

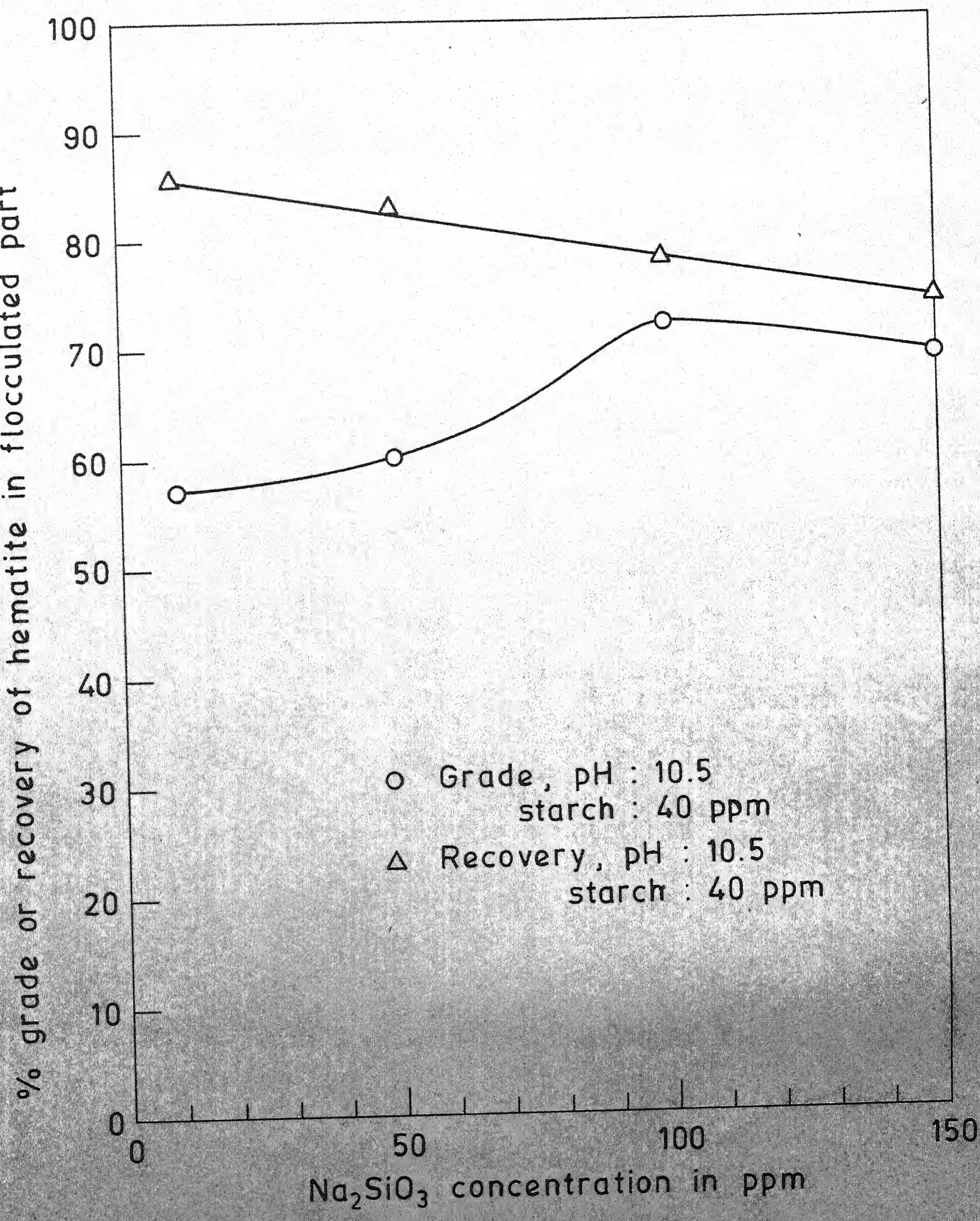


Fig. 16 - Effect of Na_2SiO_3 concentration on flocculation of synthetic mixture (≈50 : 50) of pure hematite (1-8 μ) and pure kaolinite (1-8 μ).
Ref. Table 31

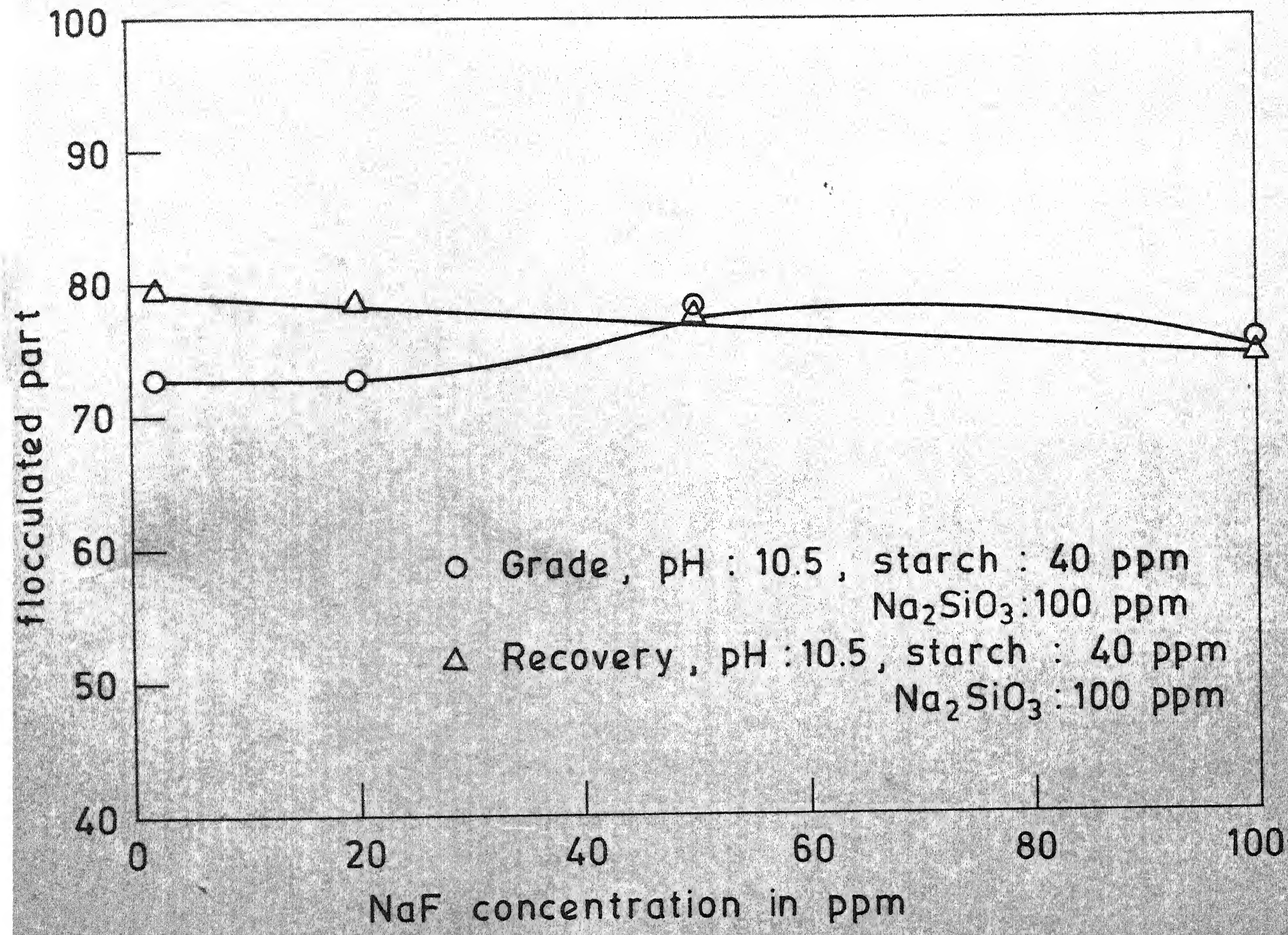


Fig. 17 - Effect of NaF on the flocculation of synthetic mixture (≈50 : 50) of pure hematite and pure kaolinite (1 - 8 μ).
Ref. Table 32

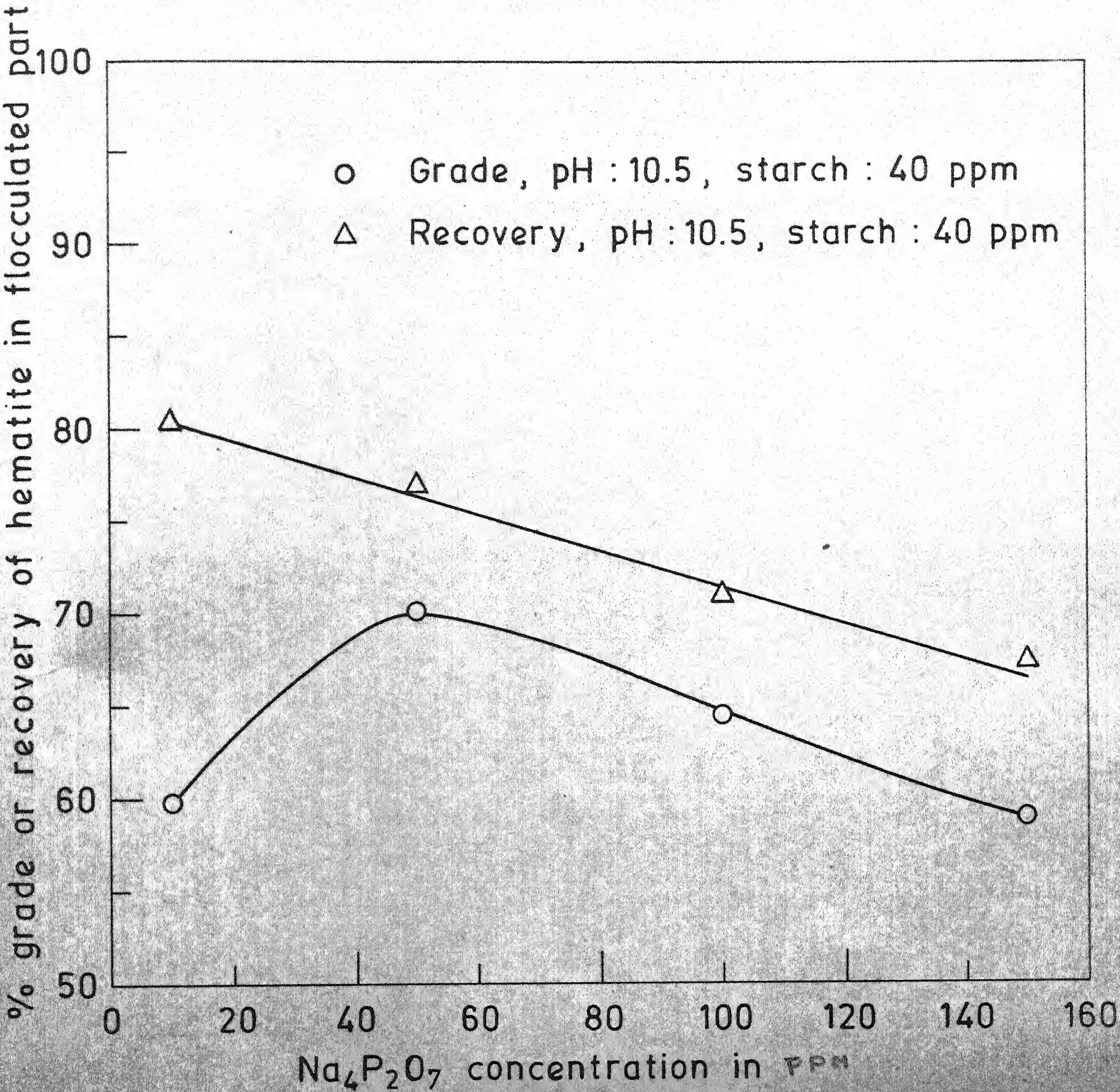


Fig. 18 - Effect of different dosage of $Na_4P_2O_7$ on the flocculation of synthetic mixture (≈50 : 50) of pure hematite and pure Kaolinite (1 - 8 μ). Ref. Table 33 .

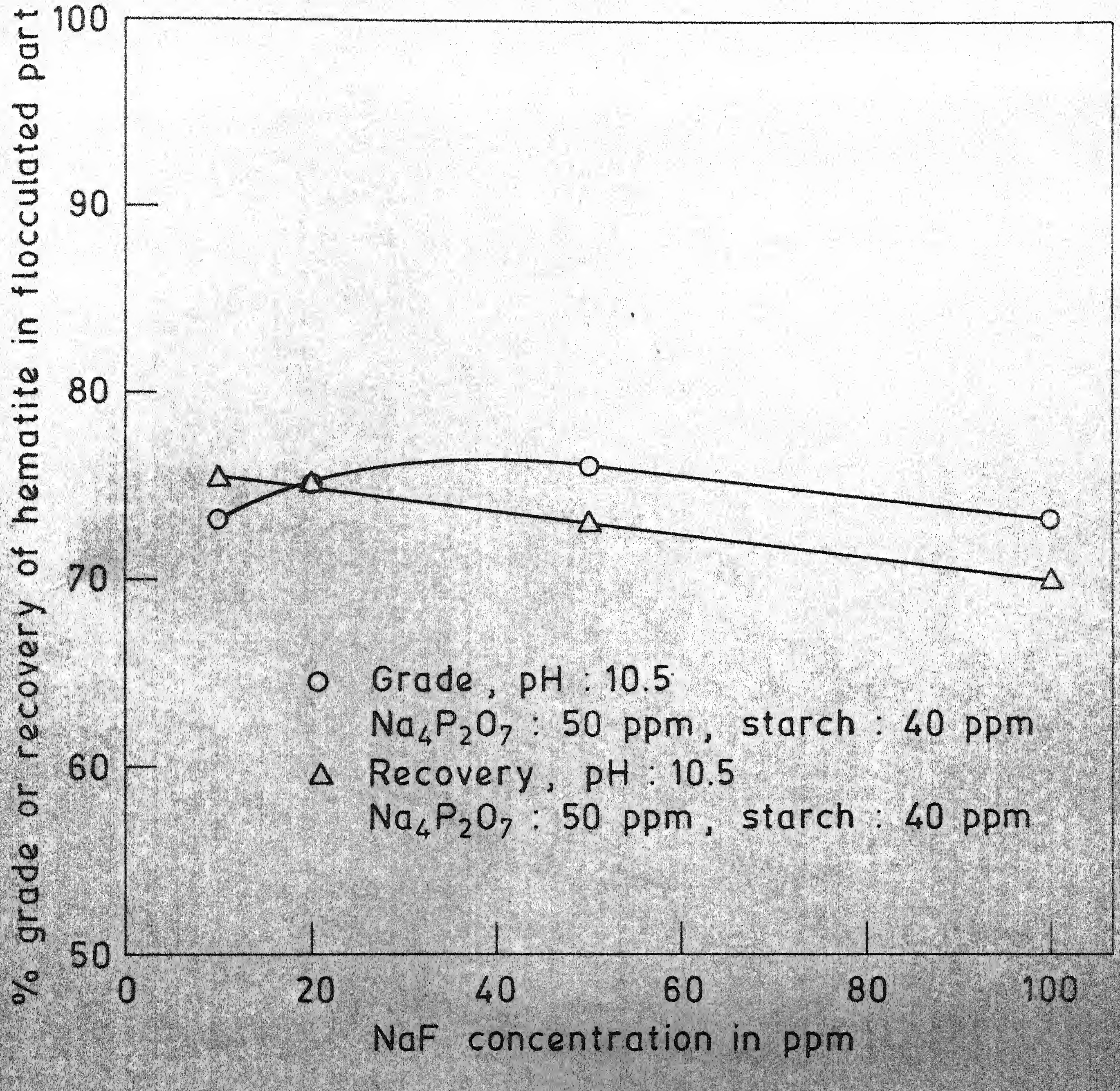


Fig. 19 - Effect of different dosages of NaF on the flocculation of synthetic mixture (≈50 : 50) of pure hematite and pure kaolinite (1 - 8 μ).
Ref. Table 34

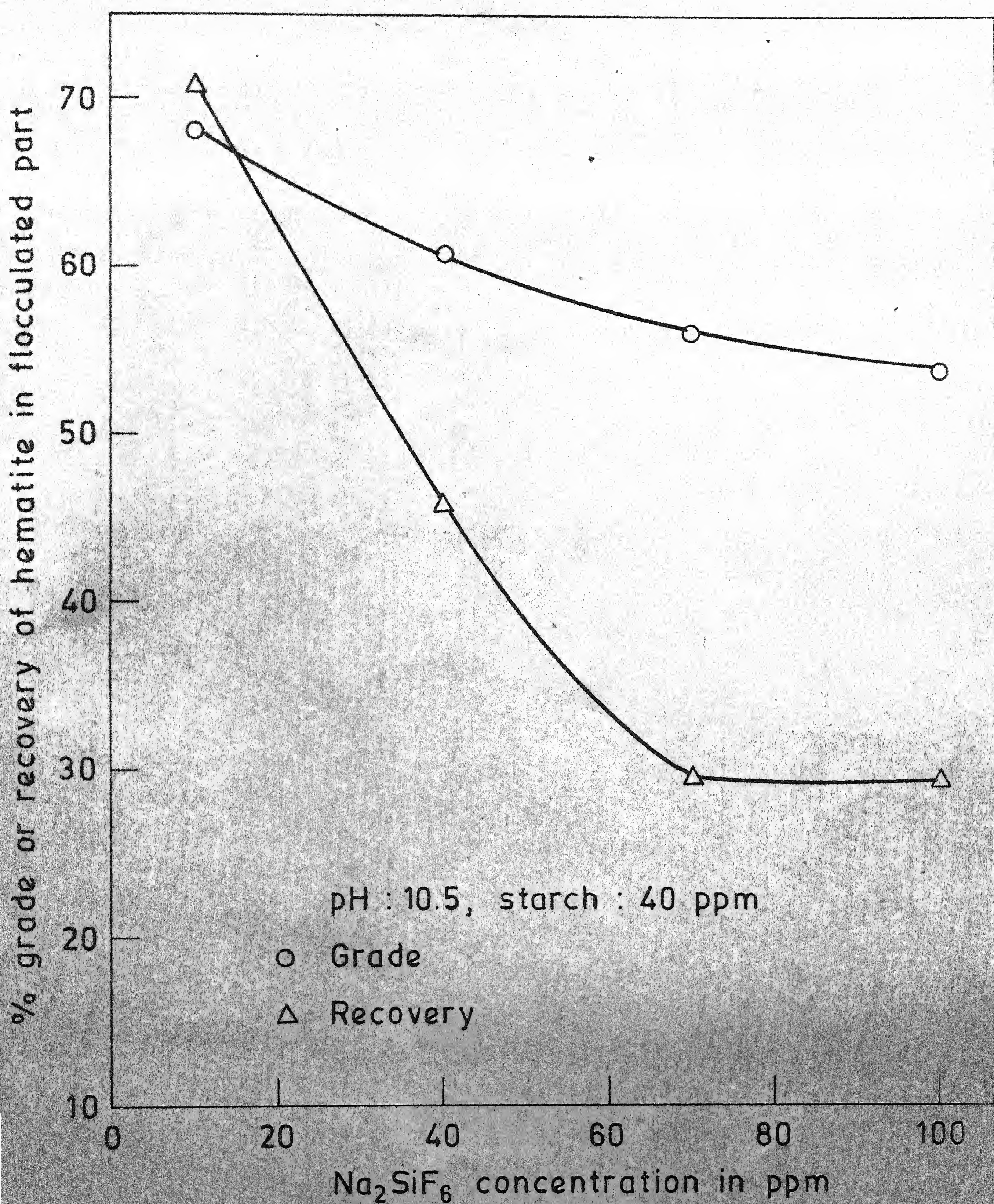


Fig. 20- Effect of different dosage of Na_2SiF_6 on the grade and recovery of hematite in flocculated part in the synthetic mixture of hematite - kaolinite (≈50 : 5
(1 - 8 μ)
Ref. Table 35

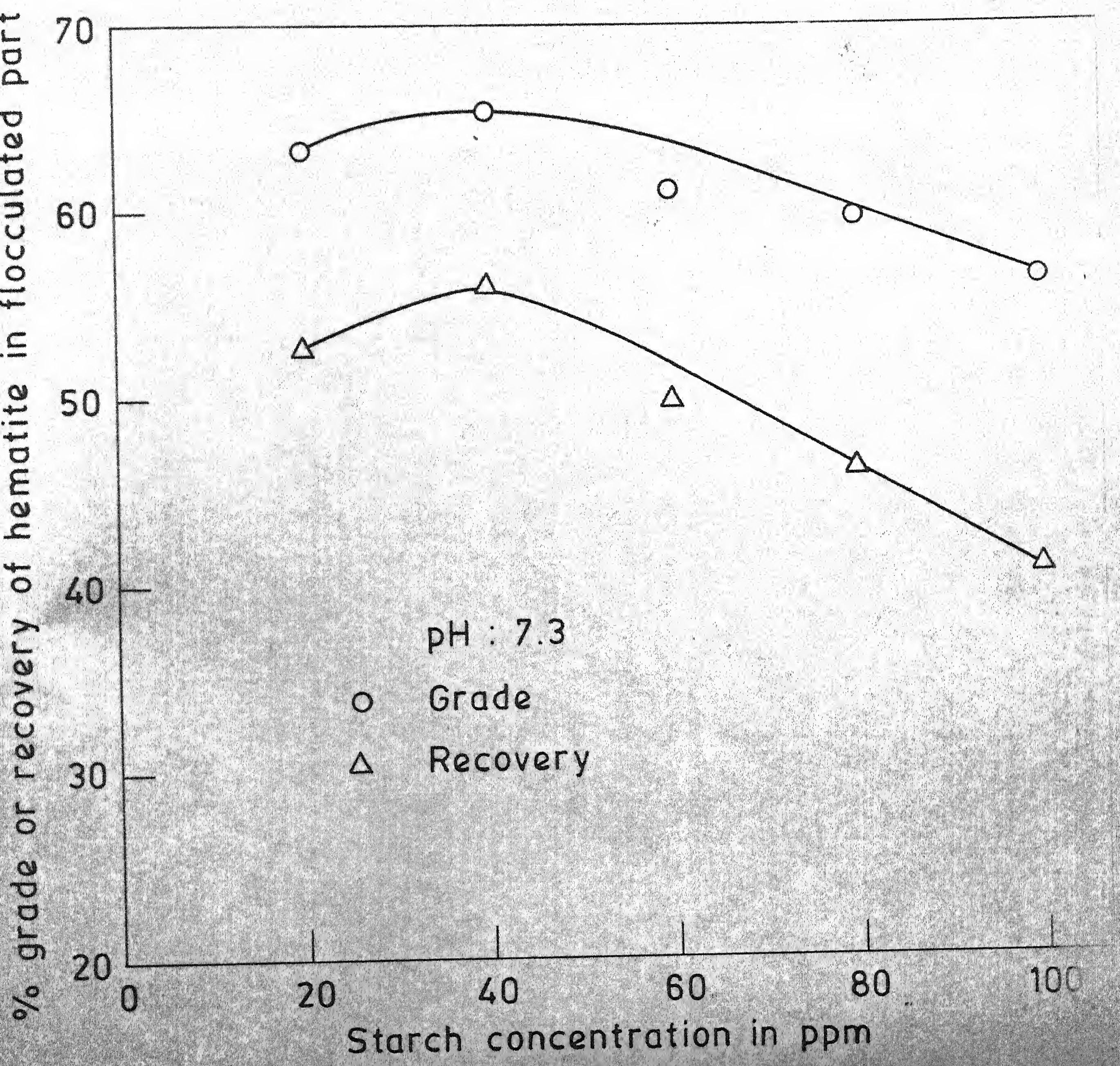


Fig. 21- Effect of different dosage of starch concentration on the grade and recovery of hematite in flocculated part in a synthetic mixture (≃50 : 50) of hematite - montmorillonite (1 - 8 μ).
Ref. Table 36

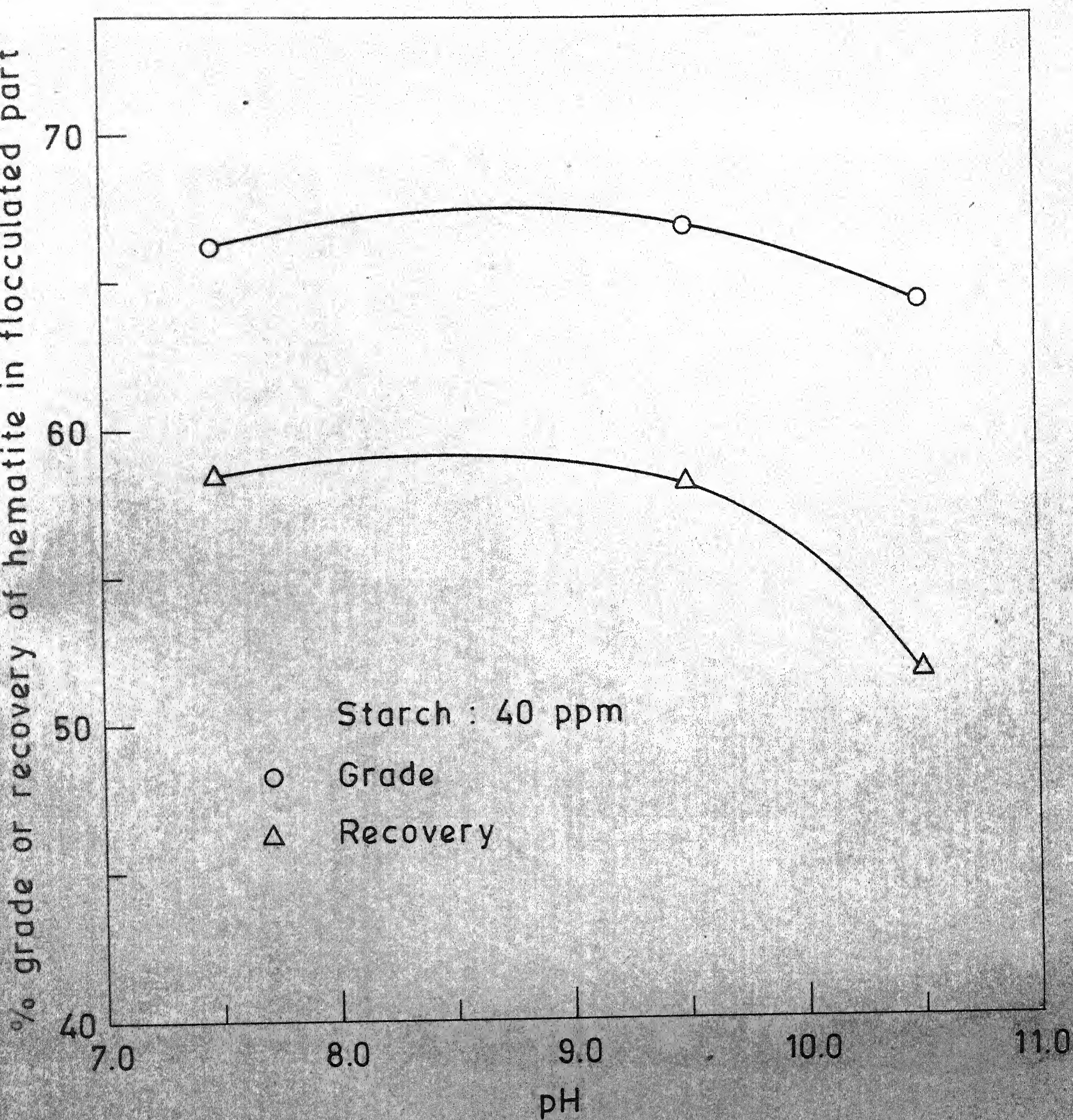


Fig. 22- Effect of pH on the grade and recovery of hematite in the flocculated part in the synthetic mixture (≈50 : 50) of hematite - montmorillonite (1 - 8 μ).
Ref. Table 37

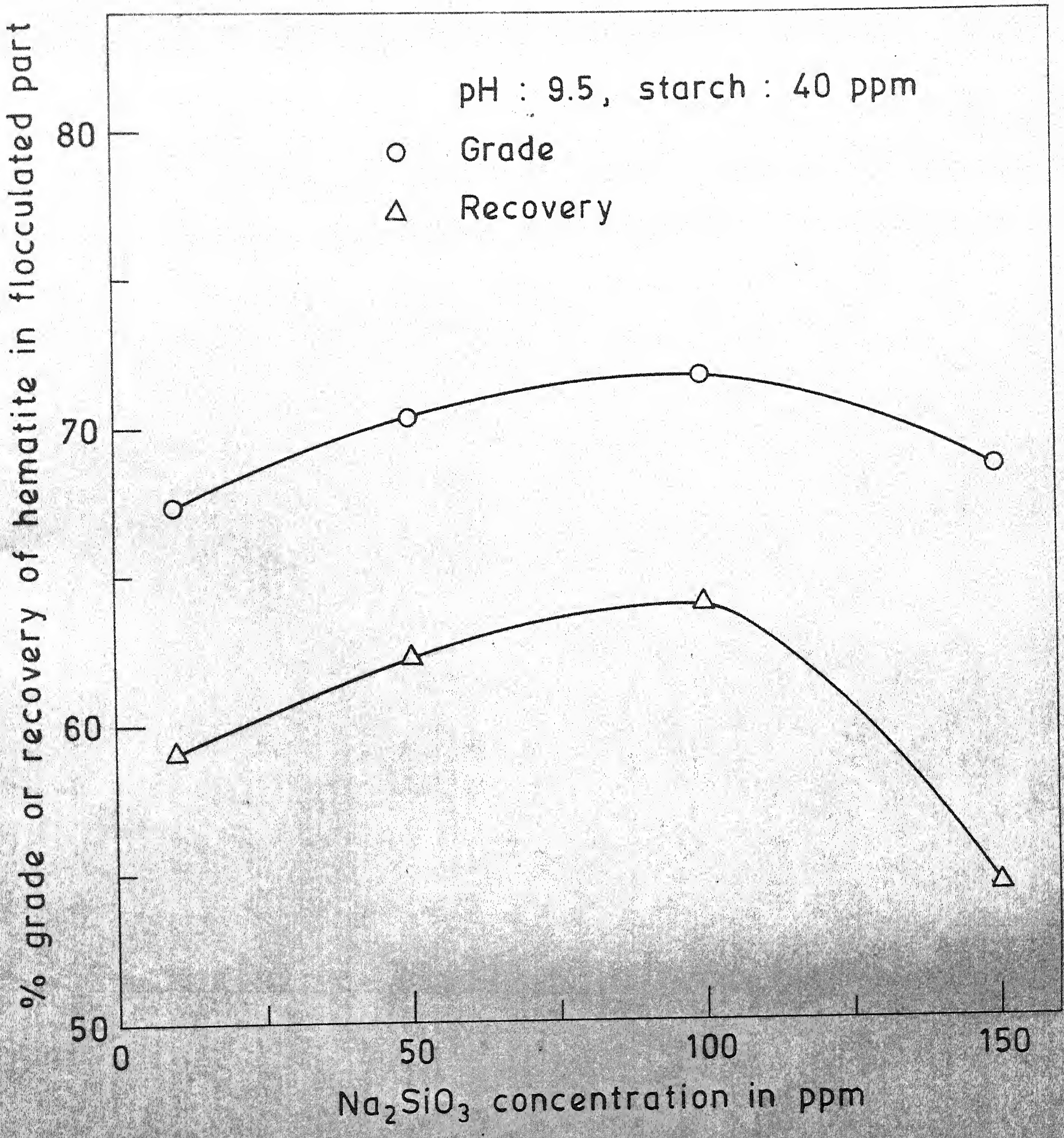


Fig. 23- Effect of different dosage of Na_2SiO_3 on the grade and recovery of hematite in flocculated part in a synthetic mixture (≈50 : 50) of hematite - montmorillonite (1 - 8 μ).
Ref. Table 38 .

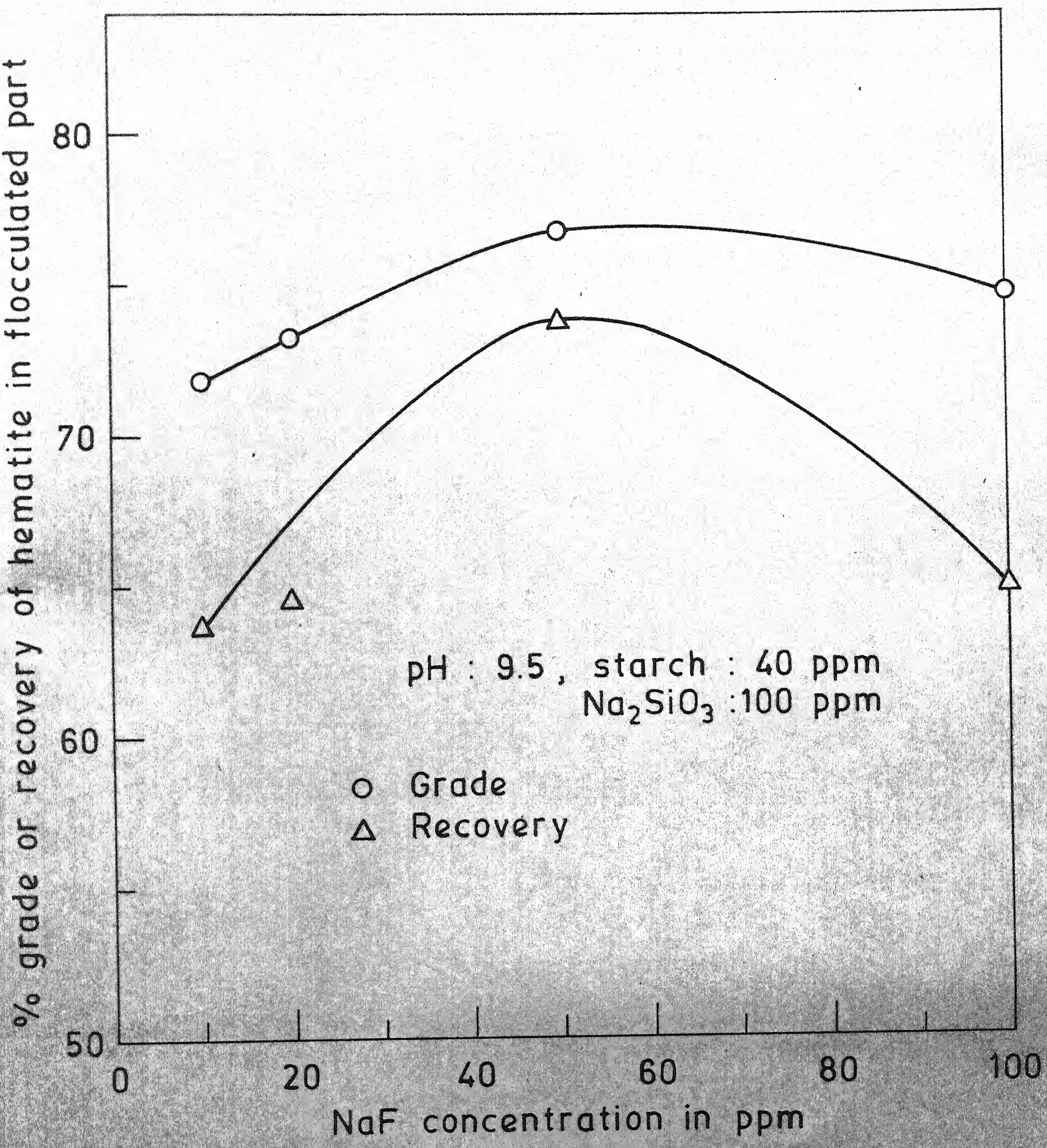


Fig. 24 - Effect of different dosage of NaF on the grade and recovery of hematite in flocculated part in a synthetic mixture (≈50 : 50) of hematite - montmorillonite (1 to 8 μ).
Ref. Table 39.

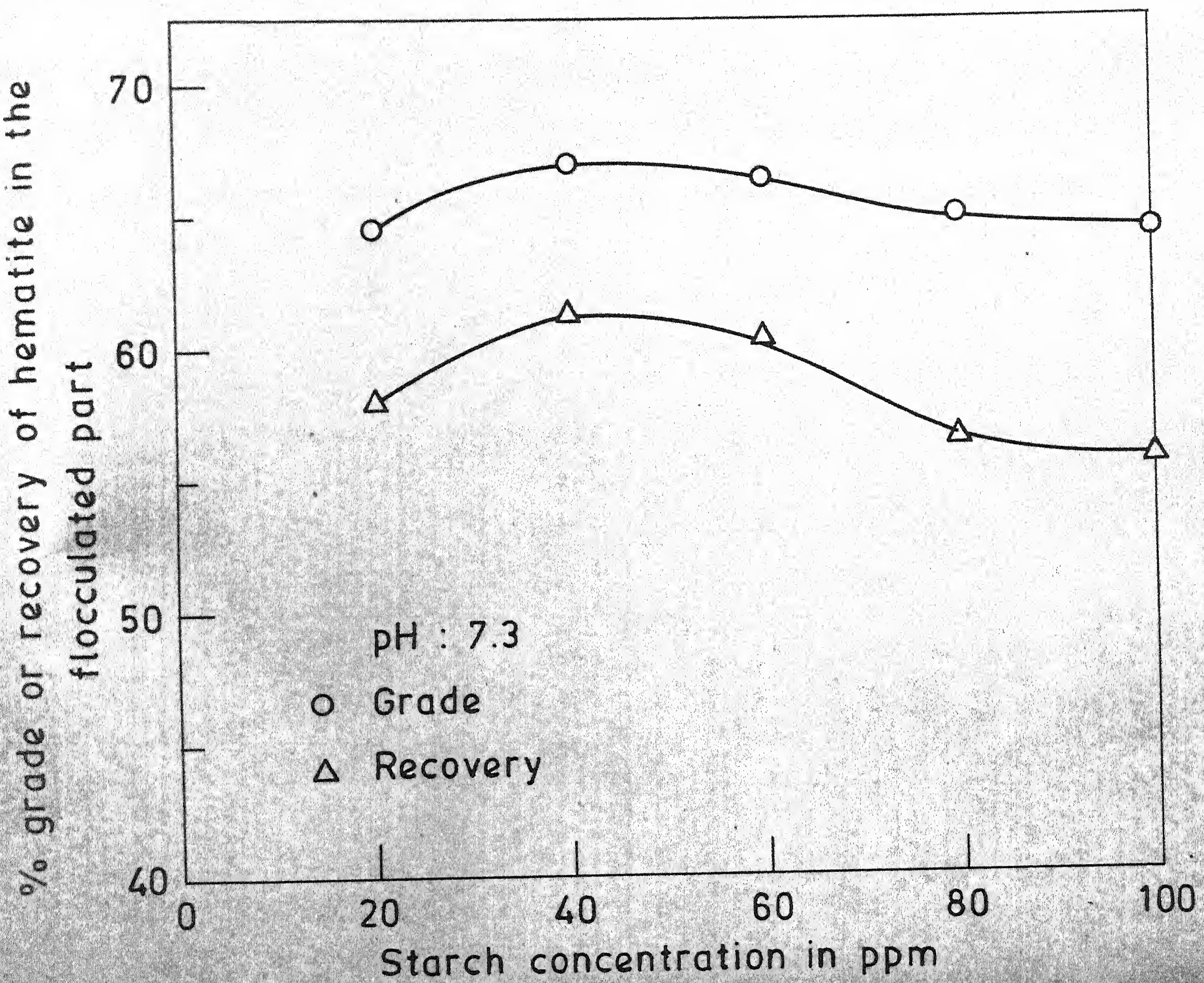


Fig. 25- Effect of different dosage of starch on the grade or recovery of hematite in flocculated part in a synthetic mixture (≈50 : 50) of hematite - illite (1 - 8 μ).
Ref. Table 40.

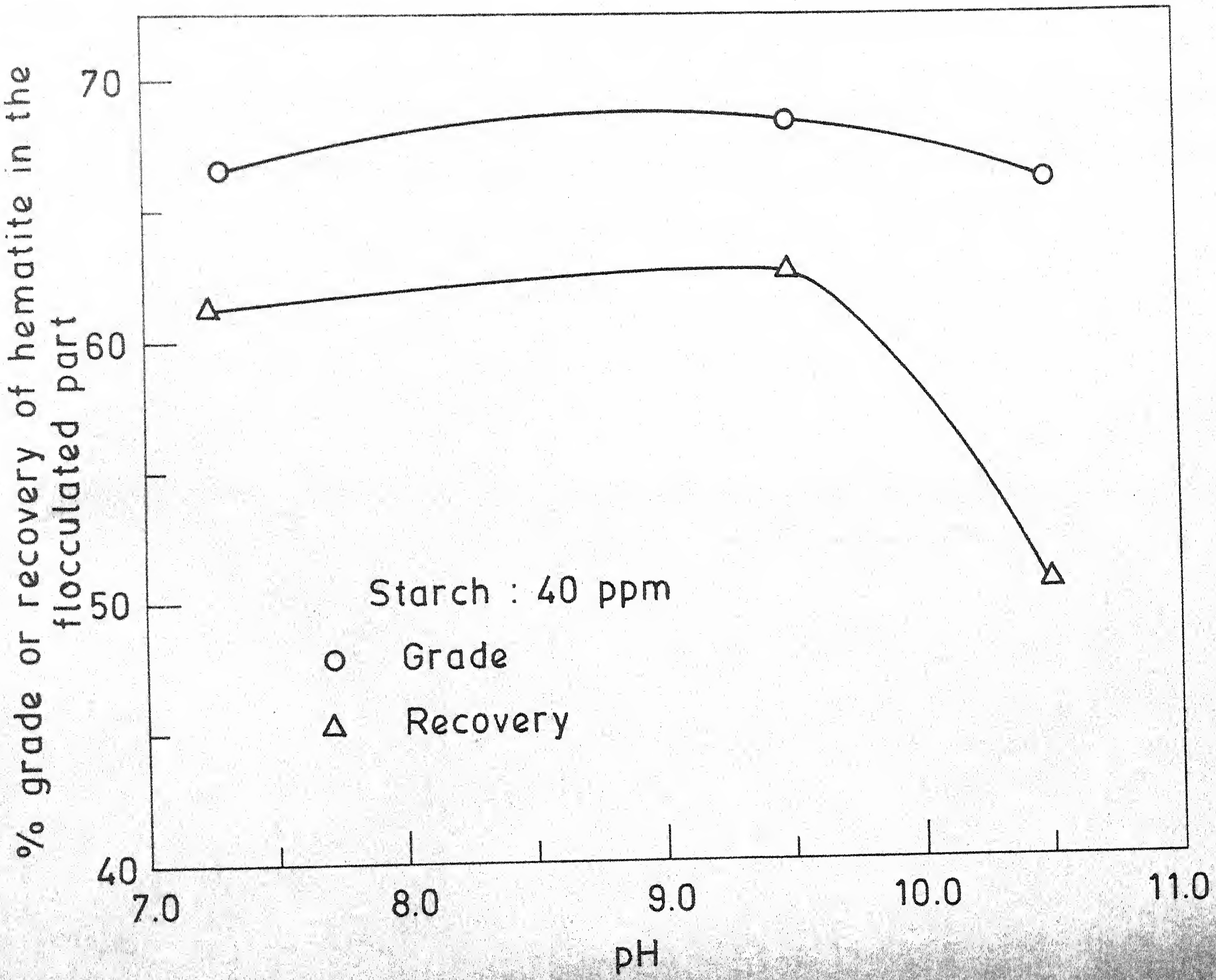


Fig. 26- Effect of pH on the grade and recovery of hematite in flocculated part in a synthetic mixture (≈50 : 50) of hematite - illite (1 - 8 μ).
Ref. Table 41

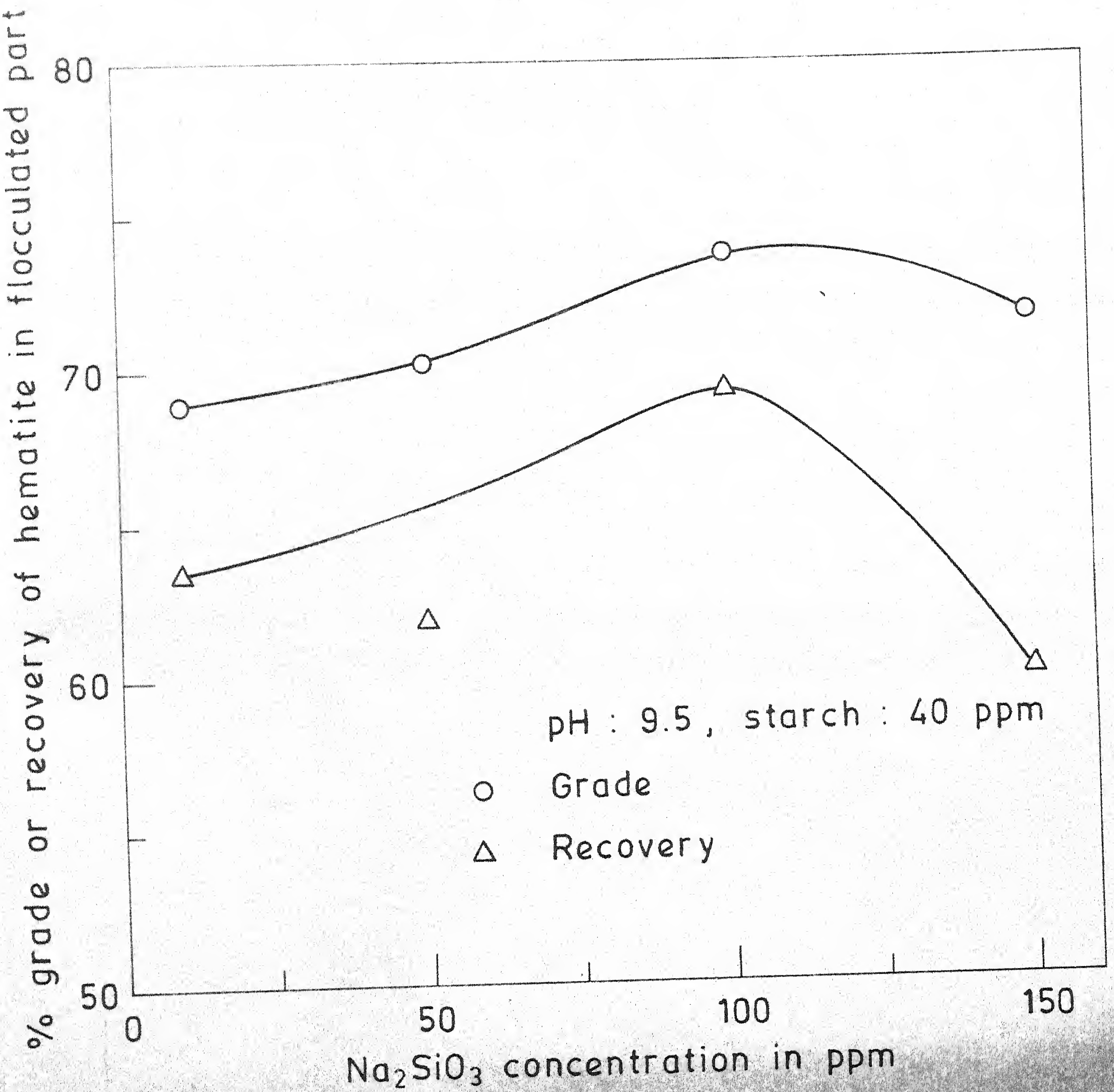


Fig. 27- Effect of different dosage of Na_2SiO_3 on the grade and recovery of hematite in flocculated part in a synthetic mixture (≈50 : 50) of hematite - illite (1 - 8 μ).
Ref. Table 42

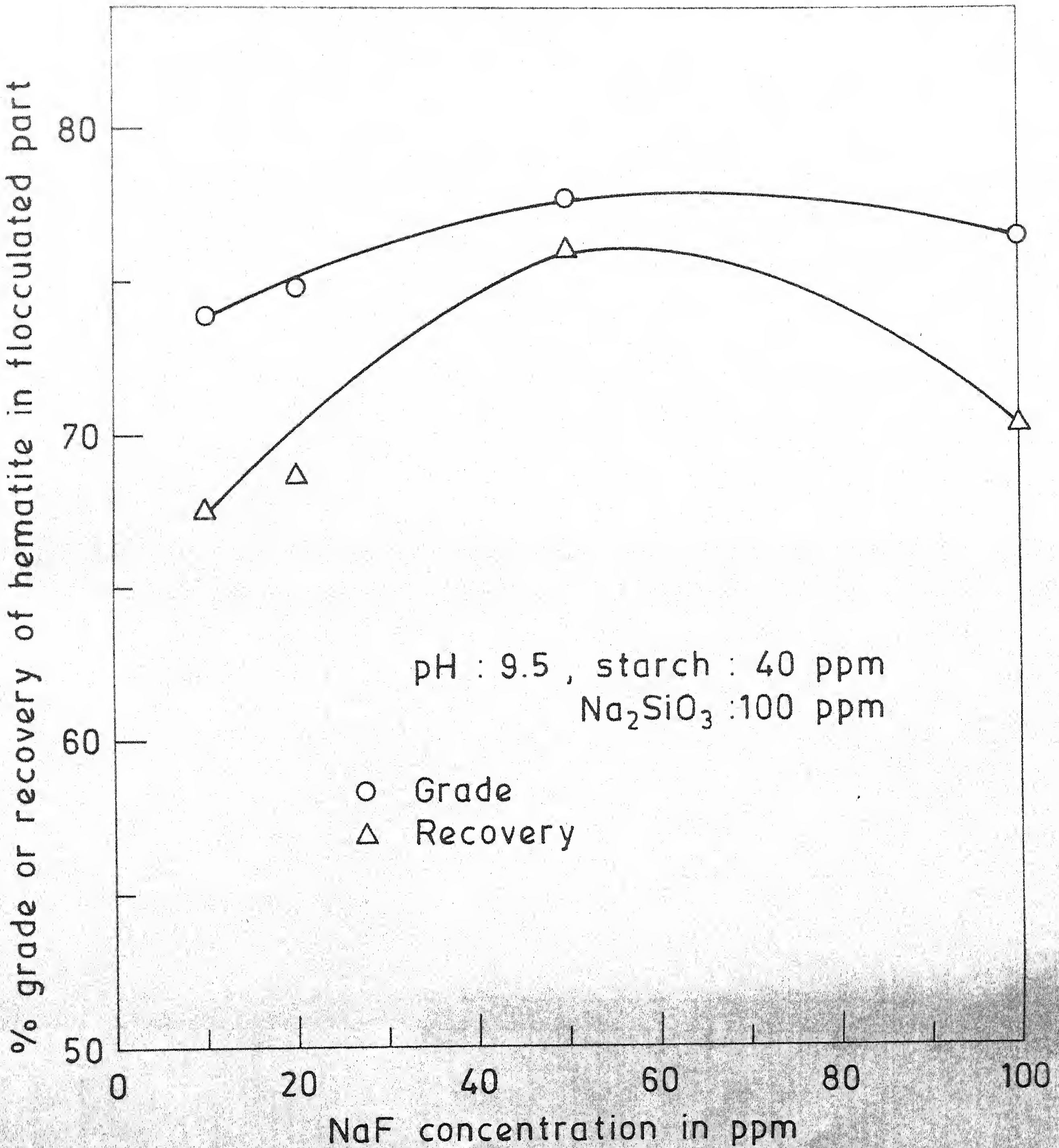


Fig. 28 - Effect of different dosage of NaF on the grade and recovery of hematite in the flocculated part in a sythetic mixture (≈50 : 50) of hematite-illite (1-8 μ).
Ref. Table 43.

TABLE 1

Stokesian Settling Time for Minerals Particles

S.No.	Minerals	Sp.Gr.	Size in μ	Settling Time Range
1	Hematite	5.68	0-2	4 hrs 58 min 10.6 secs to ∞
		''	1-8	16 min 50.8 sec. to 17 hrs 58 min 10.6 sec.
		''	2-20	2 min 41.7 sec. to 4 hr 29 min 32.6 sec.
		''	5-20	2 min 41.7 sec. to 43 min 7.6 sec.
2	Kaolinite	2.78	0-2	16 hrs 49 min 20 sec to ∞
		''	1-8	1 hr 3 min 5 sec. to 67 hr 17 min 23 sec.
		''	2-20	10 min 5.6 sec. to 16 hr 49 min 20 sec.
		''	5-20	10 min 5.6 sec to 2 hr 4 min 29.7 sec.
3	Illite	2.425	0-2	21 hr 17 min 27.8 sec. to ∞
		''	1-8	1 hr 18 min 47.9 sec to 84 hr 3 min 11.2 sec.
		''	2-20	12 min 36.4 sec to 21 hr 17 min 27.8 sec.
		''	5-20	12 min 36.4 sec to 3 hr 21 min 43.6 sec.
4	Montmorillonite	2.64	0-2	18 hr 15 min 30.5 sec. to ∞
		''	1-8	1 hr 8 min 28 sec to 73 hr 2 min 2.3 sec.
		''	2-20	10 min 57.3 sec. to 18 hr 15 min 30.5 sec.
		''	5-20	10 min. 57.3 sec. to 2 hr 55 min 16.8 sec.

TABLE 2

Flocculation of Pure Hematite (5 to 20μ) with causticised starch Solution at Normal pH using 100 PPM (Bulk concentration) of Na_2SiO_3 and Settling Time of flocs = 3 mints. (Vide Fig. 2)

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gms	pct. settled	pct. unsettled
1	0	0.8736	0.2202	1.0938	79.87	20.13
2	20	0.8932	0.1169	1.0101	88.43	11.57
3	40	1.0716	0.1092	1.1808	90.75	9.25
4	60	1.0968	0.0606	1.1574	94.76	5.24
5	80	1.0264	0.1064	1.1328	90.61	9.39
6	120	0.9926	0.1054	1.0980	90.40	9.60
7	160	0.9464	0.1386	1.0850	87.23	12.27
8	200	1.0164	0.1113	1.1277	90.13	9.87

TABLE 3

Flocculation of Pure Hematite (5 to 20μ) with Causticised Starch Solution at Normal pH Using 400 PPM (Bulk concentration) Na_2SiO_3, Time of settling = 3 minute (Vide Fig. 2)

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gms	pct. settled	pct. unsettled
1	0	0.7909	0.1390	0.9299	85.05	14.95
2	20	0.7933	0.1526	0.9459	83.87	16.13
3	40	0.8226	0.1470	0.9696	84.84	15.16
4	60	0.7629	0.1435	0.9064	84.17	15.83
5	80	0.8310	0.1757	0.0067	83.10	16.90
6	100	0.8114	0.1743	0.9857	82.32	17.68

TABLE 4

Flocculation of Pure Montmorillonite (5 to 20μ) using Causticised Starch Solution with 100 PPM of Na_2SiO_3 (bulk concentration), Settling time = 3 minutes pH of pulp = Normal (7.2). (Vide Fig. 3).

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gms	pct. settled	pct. unsettled
1	0	0.5804	0.4585	1.0389	55.87	44.13
2	20	0.5517	0.4879	1.0396	53.07	46.93
3	40	0.5285	0.4449	0.9734	54.29	45.71
4	60	0.5762	0.4529	1.0291	55.99	44.01
5	80	0.5836	0.4491	1.0327	56.51	43.49
6	100	0.5696	0.4662	1.0358	54.99	45.01

TABLE 6

Flocculation of Pure Hematite (5 to 20μ) with Non-aged, Homogenised Starch Solution at Normal pH, Using 100 PPM (Bulk concentration) of Na_2SiO_3, Time of settling = 1 minute.
(Vide Fig. 4)

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gm	pct. settled	pct. unsettled
1	0					
2	20	0.5816	0.462	1.0436	55.73	
3	40	0.5853	0.4785	1.0637	55.02	
4	60	0.6115	0.497	1.1085	55.16	
5	80	0.5833	0.500	1.0834	53.84	
6	100	0.6288	0.4302	1.0590	59.38	

TABLE 7

Flocculation of Pure Hematite (5 to 20μ) with Aged, Homogenised Starch Solution, at Normal pH, Using 100 PPM (Bulk concentration) of Na_2SiO_3, Time of Settling = 1 minute, Aging = 24 hrs. (vide Fig. 4)

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gm	pct. settled	pct. unsettled
1	0	0.6324	0.4585	1.0909	57.97	
2	20	0.6478	0.5002	1.1479	56.43	
3	40	0.6185	0.4785	1.0969	56.38	
4	60	0.5860	0.4840	1.0700	54.76	
5	80	0.5994	0.4578	1.0572	56.70	
6	100	0.6420	0.5134	1.1554	55.56	

TABLE 8

Flocculation of Pure Hematite (5 to 20μ) by Non-aged, Causticised Starch Solution, at Normal pH and Using 100 PPM of Na_2SiO_3 (bulk concentration), Time of Settling = 1 minute.
(Vide Fig. 5).

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gm	pct. settled	pct. unsettled
1	0	0.5431	0.4925	1.0355	52.45	
2	20	0.8506	0.1271	0.9777	87.00	
3	40	0.9768	0.0749	1.0517	92.89	
4	60	0.9197	0.1019	1.0210	90.03	
5	80	0.8960	0.1029	0.9989	89.70	
6	100	0.9207	0.1144	1.0351	88.94	

TABLE 9

Flocculation of Pure Hematite (5 to 20µ) with Aged, Causticised Starch Solution, at Normal pH Using 100 PPM (bulk concentration) of Na_2SiO_3, time of settling = 1 minute, Aging = 24 hrs.
(Vide Fig. 5)

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of pulp in gm	pct. settled	pct. unsettled
1	0	0.572	0.5558	1.1278	50.72	
2	20	0.7152	0.3710	1.0862	65.84	
3	40	0.7694	0.3168	1.0862	70.84	
4	60	0.7344	0.3248	1.0592	69.34	
5	80	0.7114	0.3230	1.0344	68.77	
6	100	0.7701	0.2926	1.0627	72.47	

TABLE 10

Flocculation of Pure Hematite (5 to 20μ) with Non-aged, Causticised-Homogenised Starch Solution, at Normal pH, Using 100 PPM (bulk concentration) of Na_2SiO_3, Time of settling = 1 minute. (Vide Fig. 6)

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of water in gm	pct. settled	pct. unsettled
1	0	0.7667	0.5221	1.2888	59.49	40.50
2	20	0.9897	0.1171	1.1068	89.42	10.58
3	40	0.9991	0.1159	1.1150	89.61	10.39
4	60	0.9503	0.1081	1.0584	89.78	10.22
5	80	0.9616	0.1402	1.1018	87.28	12.72
6	100	0.9516	0.1410	1.0926	87.16	12.84

TABLE 11

Flocculation of Pure Hematite (5 to 20μ) with Aged, Causticised-Homogenized Starch Solution at Normal pH, using 100 PPM (bulk concentration) of Na_2SiO_3, Time of Settling = 1 minute, Aging time = 24 hrs. (Vide Fig. 6).

Sl. No.	Dosage of Starch in ppm	Wt. of settled part in gm	Wt. of unsettled part in gm	Total wt. of material in 100 cc of water in gm	pct. settled	pct. unsettled
1	0	0.5738	0.4517	1.0255	55.95	44.05
2	20	0.9748	0.1174	1.0922	89.24	10.75
3	40	1.0609	0.1431	1.2040	88.11	11.89
4	60	0.8629	0.1550	1.0179	85.77	14.23
5	80	0.9588	0.1449	1.1037	86.08	13.92
6	100	0.9054	0.1470	1.0524	86.03	13.97

TABLE 12

Flocculation of Pure Hematite (5 to 20μ) with Non-aged, Starch Phosphate Solution, at Normal pH, using 100 PPM (bulk concentration) of Na_2SiO_3, Time of Settling = 1 minute.
(Vide Fig. 7)

Sl. No.	Dosage of Starch in ppm	Wt. of material settled in gm	Wt. of material unsettled in gm	Total wt. of material in 100 cc of water in gm	pct. settled	pct. unsettled
1	0	1.0640	0.6881	1.7521	60.72	39.28
2	1	1.5912	0.2370	1.82815	87.04	12.96
3	5	1.6306	0.1533	1.7839	91.41	8.59
4	10	1.7600	0.1089	1.8689	94.42	5.58
5	15	1.6312	0.1428	1.7740	92	8
6	20	1.6497	0.1407	1.7904	92.14	7.86
7	30	1.6386	0.1635	1.8021	90.92	9.08
8	40	1.6469	0.1614	1.8083	91.07	8.93

TABLE 13

Flocculation of Pure Hematite (5 to 20μ) using Aged, Starch Phosphate solution, at Normal pH, Using 100 PPM (bulk concentration) of Na_2SiO_3, Time of settling = 1 minute, Aging time ≅ 24 hrs (Vide Fig. 7).

Sl. No.	Dosage of Starch in ppm	Wt. of material settled in gm.	Wt. of material unsettled in gm	Total wt. of material in 100 cc of water in gm	pct. settled	pct. unse-ttled
1	0	1.1032	0.7686	1.8718	58.89	41.11
2	1	1.2573	0.7742	2.0315	61.19	38.81
3	5	1.4376	0.5600	1.9947	71.92	28.08
4	10	1.4426	0.5485	1.9911	72.45	27.55
5	15	1.6387	0.5569	2.1956	74.46	75.54
6	20	1.2211	0.5558	1.7769	68.72	31.28
7	30	1.3296	0.5960	1.9257	69.04	30.96
8	40	1.2796	0.6531	1.9327	66.20	33.80

TABLE 14

Flocculation of Pure Montmorillonite (5 to 20µ) using Non-aged Starch-Phosphate Solution, at Normal pH, using 100 PPM (bulk concentration) of Na_2SiO_3, Time of Settling = 1 minute. (Vide Fig. 7)

Sl. No.	Dosage of Starch in ppm	Wt. of material settled in gm	Wt. of material unsettled in gm	Total wt. of material in 100 cc of water in gm	pct. settled	pct. unsettled
1	0	0.4402	0.4148	0.8550	51.49	48.51
2	1	0.4914	0.4477	0.9391	52.33	47.67
3	5	0.5056	0.4302	0.9358	54.02	45.98
4	10	0.5292	0.4466	0.9758	54.23	45.77
5	15	0.5461	0.4823	1.0284	53.10	46.90
6	20	0.5346	0.3931	0.9247	57.63	42.37
7	30	0.5367	0.4305	0.9672	55.49	44.51
8	40	0.5244	0.4694	0.9938	52.77	47.33

TABLE 15

Effect of Dosage of Modified Causticised-Homogenised (MCH) Starch on Flocculation of Pure Hematite Particle (0-2μ) at 6.7 pH, Time of Settling = 1 minute.
(Vide Fig. 8)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	100	0.410	0.938	1.348	30.4
2	20	100	0.589	0.593	1.182	49.8
3	40	100	0.743	0.502	1.245	59.7
4	60	100	0.655	0.546	1.201	54.5
5	80	100	0.386	0.386	0.814	52.5
6	100	100	0.636	0.636	1.231	48.3

TABLE 16

Effect of Dosage of MCH Starch on Flocculation of Pure Hematite Particle (0–2μ) at 10.4 pH, Time of settling = 1 minute. (Vide Fig. 8)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	100	0.468	1.109	1.577	29.1
2	20	100	0.379	0.907	1.286	29.4
3	40	100	0.465	1.012	1.477	31.4
4	60	100	0.437	1.040	1.477	29.6
5	80	100	0.434	–	–	–
6	100	100	0.441	1.110	1.551	28.4

TABLE 17

Effect of Different Dosages of MCH Starch on the Flocculation of Pure Hematite (0-2μ) at 6.8 pH Without Using Any Dispersant (Na_2SiO_3), Time of settling = 1 minute
(Vide Fig. 9)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	0	0.513	0.802	1.315	39
2	40	0	1.200	0.186	1.386	86.5
3	80	0	0.717	0.182	0.899	79.7
4	120	0	1.129	0.322	1.451	77.8
5	240	0	0.902	0.452	1.354	66.6
6	400	0	0.842	0.375	1.217	69.1

TABLE 18

Effect of Different Dosages of MCH **Starch on** the Flocculation of Pure Hematite (0-2μ) at 10.5 pH Without Using Any Dispersant (Na_2SiO_3), Time of settling = 1 minute (Vide Fig. 9)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	0	0.485	0.971	1.456	33.3
2	40	0	1.387	0.142	1.529	90.7
3	80	0	1.126	0.146	1.272	88.5
4	120	0	1.273	0.350	1.623	78.4
5	240	0	1.066	0.458	1.524	69.9
6	400	0	0.624	0.682	1.306	47.6

TABLE 19

Effect of Ca^{++} Concentration on the Flocculation of Pure Hematite (0-2µ) having pH-6.8 by MCH Starch Without Using any Na_2SiO_3, Time of Settling = 1 minute
(Vide Fig. 10)

Sl. No.	Dosage of starch in ppm	Dosage of Na_2SiO_3 in ppm	Dosage of Ca^{++} in ppm	Wt. of flocc- ulated part in gm	Wt. of un- floccula- ted part in gm	Total wt. in gm	pct. floc- culated
1	40	0	0	1.008	0.147	1.155	87.2
2	40	0	20	1.088	0.147	1.235	88.9
3	40	0	40	0.860	0.109	0.969	88.7
4	40	0	60	0.995	0.158	1.153	86.3
5	40	0	80	1.272	0.140	1.412	90
6	40	0	100	1.081	0.130	1.211	89.2

TABLE 20

Effect of Ca^{++} Concentration on the Flocculation of Pure Hematite (0-2μ) having pH-10.5, by MCH Starch, Without Using any Dispersant, Time of Settling = 1 minute
(Vide Fig. 10)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Dosage of Ca^{++} in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	40	0	0	0.875	0.182	1.057	82.7
2	40	0	20	1.240	0.210	1.450	85.5
3	40	0	40	2.031	0.182	2.213	91.8
4	40	0	60	2.130	0.161	2.291	92.9
5	40	0	80	1.631	0.186	1.817	89.7
6	40	0	100	1.549	0.147	1.696	91.3

TABLE 21

Effect of Different Dosages of MCH Starch as Flocculant on the Pure Hematite (1-8μ) at pH 7.3, Time of settling = 1 minute (Vide Fig. 11)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	40	0.189	0.553	0.742	25.4
2	20	40	0.468	0.081	0.549	85.2
3	40	40	0.601	0.074	0.675	89.03
4	60	40	0.558	0.161	0.719	77.6
5	80	40	0.590	0.193	0.783	75.3
6	100	40	0.653	0.165	0.818	74.3

TABLE 22

Effect of Different Dosages of MCH Starch on Flocculation of Pure Hematite (1-8μ) at 10.5 pH.
Time of settling = 1 minute
(Vide Fig. 11)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	40	0.252	0.613	0.865	29.1
2	20	40	0.742	0.074	0.816	90.9
3	40	40	0.723	0.116	0.839	86.1
4	60	40	0.806	0.123	0.929	86.7
5	80	40	0.609	0.211	0.820	74.2
6	100	40	0.622	0.242	0.864	71.9

TABLE 23

Effect of Na_2SiO_3 Concentration on Pure Hematite (1-8μ) at pH - 7.3, Using Modified Causticised-Homogenised Starch Solution (MCH), Time of settling = 1 minute
(Vide Fig. 12)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	40	0	0.726	0.070	0.796	91.2
2	40	20	0.662	0.021	0.683	96.9
3	40	40	0.627	0.081	0.708	89.06
4	40	60	0.883	0.074	0.957	92.2
5	40	80	0.714	0.098	0.812	87.9
6	40	100	0.754	0.086	0.840	89.7

TABLE 24

Effect of Different Dosages of Na_2SiO_3 on the Flocculation of Pure Hematite (1-8μ) at pH 7.3 by MCH Starch Solution, Time of Settling = 1 minute (Vide Fig. 12)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	60	0	0.644	0.039	0.683	94.3
2	60	20	0.544	0.091	0.635	85.6
3	60	40	0.634	0.105	0.739	85.7
4	60	60	0.836	0.081	0.917	91.1
5	60	80	0.615	0.133	0.798	82.2
6	60	100	0.737	0.091	0.828	89.6

TABLE 25

Effect of Ca^{++} Concentration on Flocculation of Pure Hematite (1-8μ) at 7.3 pH by Modified Causticised-Homogenised Starch as Flocculant
Time of settling = 1 minute
(Vide Fig. 13)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Ca^{++} concentration in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	40	40	0	0.897	0.081	0.978	91.7
2	40	40	20	0.804	0.084	0.888	90.5
3	40	40	40	0.568	0.095	0.663	85.6
4	40	40	60	0.615	0.140	0.755	81.5
5	40	40	80	0.611	0.102	0.713	85.7
6	40	40	100	0.754	0.088	0.842	89.5

TABLE 26

Effect of Ca^{++} Concentration on Flocculation of Pure Hematite (1-8μ) at pH 7.3 by Modified Causticised-Homogenised (MCH) Starch as Flocculant, Time of settling = 1 minute (Vide Fig. 13)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Ca^{++} concentration in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	60	40	0	0.595	0.095	0.690	86.2
2	60	40	20	0.833	0.074	0.907	91.8
3	60	40	40	0.464	0.221	0.685	68.8
4	60	40	60	0.967	0.126	1.093	88.6
5	60	40	80	1.161	0.105	1.266	91.7
6	60	40	100	0.904	0.059	1.063	85.04

TABLE 27

Effect of Different Dosages of Modified Causticised-Homogenised (MCH) Starch (as Flocculant) on the Flocculation of Pure Hematite (2-20μ) at pH 7.2, Time of Settling = 1 minute
(Vide Fig. 14)

Sl. No.	Dosage of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	100	0.425	0.812	1.237	34.3
2	20	100	0.754	0.179	0.933	80.8
3	40	100	0.856	0.102	0.958	89.2
4	60	100	1.028	0.105	1.133	90.7
5	80	100	0.942	0.121	1.063	88.6
6	100	100	0.663	0.432	1.095	61.1

TABLE 28

Effect of Different Dosages of Modified Causticised-[illegible]nised (MCH) Starch (as Flocculant) on the Flocculation of Pure Hematite (2-20μ) at 10.5 pH.
Time of settling = 1 minute
(Vide Fig. 14)

Sl. No.	Dosages of Starch in ppm	Dosage of Na_2SiO_3 in ppm	Wt. of flocculated part in gm	Wt. of unflocculated part in gm	Total wt. in gm	pct. flocculated
1	0	100	0.837	1.908	2.745	30.4
2	20	100	2.300	0.816	3.116	73.8
3	40	100	2.348	0.513	2.861	82.6
4	60	100	1.249	1.6905	2.939	45.8
5	80	100	2.004	0.983	2.987	67.9
6	100	100	0.840	1.915	2.255	37.2

TABLE 29

Flocculation of Synthetic Mixture (50:50) of Hematite and Kaolinite (1-18 μ), NaF and Na-silicate are not use, time of settling = 1 minute, single Stage Flocculation is done here. MCH Starch was used.

Dosage of Starch in ppm	pH of pulp	Total wt. of Fe_2O_3 in pulp gm	Total wt. of Kaolinite in pulp in gm.	FLOCCULATED PART: Wt. of Fe_2O_3 in floc part in gm	Wt. of Kaolinite in floc part in gm	Grade % Fe_2O_3	Grade % Kaolinite	Recovery % Fe_2O_3	Recovery % Kaolinite	UNFLOCCULATED PART: Wt. of Fe_2O_3 in unfloc part	Wt. of Kaolinite in unfloc part	Grade % Fe_2O_3	Grade % Kaolinite	Recovery % Fe_2O_3	Recovery % Kaolinite	Selectivity Index (C.S.I.)
10	7.3	8.234	8.178	3.31	2.407	57.9	42.1	40.2	29.42	4.924	5.771	46.04	53.96	59.8	70.58	1.4
20	7.3	8.468	8.436	5.606	2.429	69.7	30.3	66.2	28.8	2.862	6.007	32.14	67.86	33.8	71.2	2.2
40	7.3	8.272	8.235	7.875	6.68	54.1	45.9	95.2	81.12	0.397	1.554	20.35	79.65	4.8	18.82	2.14
40	10.5	8.168	8.161	7.049	5.419	56.5	43.5	86.3	66.4	1.119	2.742	28.9	71.1	13.7	33.6	1.7

TABLE 30

3-Stage Flocculation of Synthetic Mixture (50:50) of Hematite and Pure Kaolinite (1-8) with 20 ppm MCH Starch Solution (bulk Concentration), pH 7.3, Fe_2O_3 = 8.468 gm, Kaolinite = 8.436 gm, Time of settling = 1 minute, pulp density = 1, Na_2SiO_3, NaF is not used

. of tage	FLOCCULATED PART						UNFLOCCULATED PART						Selectivity Index
	Wt. of Fe_2O_3 in floc in gm	Wt. of Kaolinite in floc in gm	Grade		Recovery		Wt. of Fe_2O_3 in unfloc part in gm	Wt. of Kaolinite in unfloc phased part in gm	Grade		Recovery		
			% Fe_2O_3	% Kaolinite	% Fe_2O_3	% Kaolinite			% Fe_2O_3	% Kaolinite	% Fe_2O_3	% Kaolinite	
	5.606	2.429	69.7	30.3	66.2	28.8	2.862	6.007	32.14	67.86	33.8	71.2	2.2
	4.625	1.608	74.2	25.5	54.62	19.06	0.262	0.661	29.9	70.1	3.09	7.14	2.59
	4.028	1.364	74.7	25.3	47.56	16.17	0.017	0.041	29.2	70.8	0.002	0.005	2.67
	0.842	1.466	36.48	63.52	9.94	17.38	0.176	0.700	20.1	79.9	2.07	8.3	1.5

TABLE 31

Flocculation of Synthetic Mixture (50:50) of Pure Hematite and Pure Kaolinite (1-8 , pulp density = 1) at 10.5 pH and Bulk MCH Starch Concentration of 40 PPM. Time of settling allowed = 1 minute, Single stage experiment is done, Time of mixing for Na_2SiO_3 = 7 minute, (vide Fig. 16)

Dosage of Na_2SiO_3 in ppm	Total wt. of Hematite in the pulp in gm	Total wt. of Kaolinite in the pulp in gms	FLOCCULATED PART wt. of Hematite in floc part in gm	Wt. of Kaolinite in floc part in gm	Grade % Fe_2O_3	% Kaolinite	Recovery % Fe_2O_3	% Kaolinite	UNFLOCCULATED PART Wt. of Hematite in unfloc part in gm	Wt. of Kaolinite in unfloc part in gm	Grade % Fe_2O_3	% Kaolinite	Recovery % Fe_2O_3	% Kaolinite	Selectivity Index CSI
10	8.304	8.162	7.117	5.325	57.2	42.8	85.7	65.24	1.187	2.837	29.5	70.5	14.3	34.76	1.787
50	8.297	8.167	6.887	4.553	60.2	39.8	83	55.75	1.410	3.614	28.06	71.94	17	44.25	1.969
100	8.309	8.158	6.489	2.486	72.3	27.7	78.1	30.47	1.815	5.672	24.2	75.8	21.9	69.53	2.859
150	8.321	8.169	6.190	2.755	69.2	30.8	74.4	33.73	2.131	5.414	28.24	71.76	25.6	66.27	2.38

TABLE 32

Flocculation Experiment with Synthetic Mixture (50:50) of Pure Hematite and Pure Kaolinite (1-8 μ) at pH - 10.5 using Bulk MCH Starch Concentration = 40 PPM, Bulk Na_2SiO_3 Concentration = 100 PPM, Settling time of flocs = 1 minute, Single stage experiment is done. Time of Stirring after addition of Na_2SiO_3 = 7 minute, Time of mixing for NaF = 1 minute, (Vide Fig. 17)

Dosage of NaF in ppm	Wt. total of Hematite in gm	Total wt. of Kaolinite in floc in gm	FLOCCULATED PART: Wt. of Hematite in floc in gm	Wt. of Kaolinite in floc in gm	Grade % Fe_2O_3	Grade % Kaolinite	Recovery % Fe_2O_3	Recovery % Kaolinite	UNFLOCCULATED PART: Wt. of Hematite in unfloc part in gm	Wt. of Kaolinite in unfloc part in gm	Grade % Fe_2O_3	Grade % Kaolinite	Recovery % Fe_2O_3	Recovery % Kaolinite	Seletivity Index
2	8.056	8.132	6.380	2.408	72.6	27.4	79.2	29.6	1.676	5.724	22.65	77.35	20.8	70.4	3.008
20	8.023	8.106	6.314	2.300	73.3	26.7	78.7	28.37	1.709	5.806	22.74	77.26	21.30	71.63	3.054
50	8.087	8.096	6.316	1.761	78.2	21.8	78.1	21.75	1.771	6.335	21.85	78.15	21.9	78.25	3.58
100	8.073	8.103	6.450	2.093	75.5	24.5	74.9	25.8	1.623	6.010	21.26	78.74	20.1	74.2	3.378

TABLE 33

Flocculation of Synthetic Mixture (50:50) of Hematite-Kaolinite (1-8,) at 10.5 pH and 40 PPM (Buld concentration) Starch, Pulp density = 1, Time of Settling = 1 minute Single Stage Flocculation, MCH Starch is used, Mixing Time for $Na_4P_2O_7$ = 7 minutes, (Vide Fig. 18)

Dosage of $Na_4P_2O_7$ in ppm	Total wt. of Hematite in gm	Total wt. of Kaolinite in gm	FLOCCULATED PART: Wt. of Hematite in floc in gm	FLOCCULATED PART: Wt. of Kaolinite in floc in gm	FLOCCULATED PART: Grade % Fe_2O_3	FLOCCULATED PART: Grade % Kaolinite	FLOCCULATED PART: Recovery % Fe_2O_3	FLOCCULATED PART: Recovery % Kaolinite	UNFLOCCUATED PART: Wt. of Hematite in unfloc part in gm	UNFLOCCUATED PART: Wt. of Kaolinite in unfloc part in gm	UNFLOCCUATED PART: Grade % Fe_2O_3	UNFLOCCUATED PART: Grade % Kaolinite	UNFLOCCUATED PART: Recovery % Fe_2O_3	UNFLOCCUATED PART: Recovery % Kaolinite	Selectivity Index
10	8.431	8.249	6.779	4.576	59.7	40.3	80.4	55.97	1.652	3.673	31.02	68.98	19.6	44.53	1.815
50	8.145	8.102	6.255	2.668	70.1	29.9	76.8	32.93	1.89	5.434	25.81	74.19	23.2	67.07	2.596
100	8.268	8.316	5.887	3.226	64.6	35.4	71.2	38.79	2.381	5.09	31.87	68.13	28.8	61.21	1.975
150	8.372	8.324	5.651	3.943	58.9	41.1	67.5	47.36	2.721	4.381	38.31	61.69	32.5	52.64	1.519

TABLE 34

Flocculation of Synthetic Mixture (50:50) of Hematite-Kaolinite (1-8 , Pulp density = 1) at 10.5 pH, Starch = 40 PPM, $Na_4P_2O_7$ = 50 PPM, Time of Settling = 1 minute, Single Stage flocculation, MCH Starch is used, mixing time for $Na_4P_2O_7$ = 7 minute, mixing time for NaF = 1 minute, (Vide Fig. 19)

Dosage of NaF in ppm	Total wt. of Hematite in gm	Total wt. of Kaolinite in gm	FLOCCULATED PART						UNFLOCCULATE PART						Selectivity Index
			Wt. of Hematite in floc in gm	Wt. of Kaolinite in floc in gm	Grade		Recovery		Wt. of Hematite in unfloc part in gm	Wt. of Kaolinite in unfloc part in gm	Grade		Recovery		
					% Fe_2O_3	% Kaolinite	% Fe_2O_3	% Kaolinite			% Fe_2O_3	% Kaolinite	% Fe_2O_3	% Kaolinite	
10	8.217	8.201	6.212	2.251	73.4	26.6	75.6	27.45	2.005	5.95	25.2	74.8	24.4	72.55	2.862
20	8.238	8.139	6.195	2.032	75.3	24.7	75.2	24.97	2.043	6.107	25.07	74.93	24.8	75.04	3.018
50	8.219	8.209	6.131	1.926	76.1	23.9	74.6	23.46	2.088	6.283	24.94	75.06	25.4	76.54	3.096
100	8.315	8.296	5.829	1.953	74.9	25.1	70.1	23.54	2.486	6.343	28.16	71.84	29.9	76.46	2.759

TABLE 35

Flocculation of Synthetic Mixture (50:50) of Hematite-Kaolinite (1-8 μ), Pulp Density = 1 at pH = 10.5, MCH Starch is used, time of settling = 1 minute, Mixing time for Na_2SiO_3 = 7 minute, Single stage, (Vide Fig. 20)

Dosage of Na_2SiO_3 in ppm	Total wt. of Hematite in gm	Total wt. of Kaolinite in gm	FLOCCULATED PART						UNFLOCCULATED PART						Selectivity Index
			Wt. of Hematite in floc in gm	Wt. of Kaolinite in floc in gm	Grade		Recovery		Wt. of Hematite in unfloc part in gm	Wt. of Kaolinite in unfloc part in gm	Grade		Recovery		
					% Fe_2O_3	% Kaolinite	% Fe_2O_3	% Kaolinite			% Fe_2O_3	% Kaolinite	% Fe_2O_3	% Kaolinite	
10	8.104	8.002	5.73	2.672	68.2	31.8	70.7	33.4	2.374	5.33	30.82	69.18	29.3	66.6	2.19
40	8.168	8.066	3.750	2.428	60.7	39.3	45.91	30.1	4.418	5.638	43.93	56.07	54.09	69.9	1.4
70	8.137	8.132	3.101	2.407	56.3	43.7	38.11	29.6	5.036	5.725	46.80	53.20	61.89	70.4	1.2
100	8.109	8.101	2.794	2.390	53.9	46.1	39.96	29.5	5.315	5.711	48.20	51.80	66.54	70.5	1.12

TABLE 36

Flocculation of Synthetic Mixture (50:50) of Hematite-Montmorillonite (1-8 μ, pulp density = 1) by MCH Starch, at 7.3 pH, time of settling = 1 minute, Single stage, (Vide Fig. 21).

Dosage of starch in ppm	Total wt. of hematite in gm	Total wt. of Mont. in gm	FLOCCULATED PART: Wt. of Hematite in floc in gm	Wt. of Mont. in floc in gm	Grade % Fe_2O_3	Grade % Mont.	Recovery % Fe_2O_3	Recovery % Mont.	UNFLOCCULATED PART: Wt. of Hematite in unfloc part in gm	Wt. of Mont. in unfloc in gm	Grade % Fe_2O_3	Grade % Mont.	Recovery % Fe_2O_3	Recovery % Mont.	Selectivity Index
20	8.168	8.176	4.297	2.502	63.2	36.8	52.6	30.6	3.871	5.674	40.56	59.44	47.4	69.4	1.59
40	8.186	8.174	4.569	2.428	65.3	34.7	55.8	29.7	3.617	5.746	38.63	61.27	44.27	70.3	1.73
60	8.180	8.176	4.084	2.594	61.1	38.9	49.92	31.8	4.096	5.577	42.34	57.66	50.08	68.2	1.46
80	8.216	8.201	3.799	2.575	59.6	40.4	46.23	31.4	4.917	5.626	43.98	56.02	53.77	68.6	1.37
100	8.196	8.186	3.343	2.595	56.3	43.7	40.79	31.7	4.853	5.591	46.47	53.53	59.21	68.3	1.22

TABLE 37

Flocculation of Synthetic Mixture (50:50) of Hematite-Montmorillonite (1-8 μ, Pulp Density = 1) by MCH Starch = 40 PPM, Time of settling = 1 minute, single phase, (Vide Fig. 22)

pH	Total wt. of Hematite in gm	Total wt. of Mont. in gm	FLOCCULATED PART: wt. of Hematite floc in gm	wt. of Mont. in floc in gm	Grade % Fe_2O_3	Grade % Mont.	Recovery % Fe_2O_3	Recovery % Mont.	UNFLOCCULATED PAR: wt. of Hematite in unfloc part in gm	wt. of Mont. in unfloc in gm	Grade % Fe_2O_3	Grade % Mont.	Recovery % Fe_2O_3	Recovery % Mont.	Selectivity Index
.5	8.232	8.246	4.807	2.466	66.1	33.9	58.4	29.9	3.425	5.78	37.21	62.79	41.6	70.1	1.8
.5	8.214	8.206	4.773	2.372	66.8	33.2	58.1	28.9	3.441	5.834	37.1	62.9	41.9	71.1	1.85
.5	8.168	8.176	4.226	2.347	64.3	35.7	51.74	28.7	3.942	5.829	40.34	59.66	48.26	71.3	1.63

TABLE 38

Flocculation of Synthetic Mixture (50:50) of Hematite-Montmorillonite (1-8 μ, Pulp density = 1) by MCH Starch = 40 PPM, pH = 9.5, Time of settling = 1 minute, Single stage, Time for Na_2SiO_3 mixing = 7 minute (Vide Fig. 23)

Dosage of Na_2SiO_3 in ppm	Total wt. of Hematite in gm	Total wt. of Mont. in gm	FLOCCULATED PART						UNFLOCCULATED PART						Selectivity Index
			Wt. of Hematite floc in gm	Wt. of Mont. in floc in gm	Grade % Fe_2O_3	Grade % Mont.	Recovery % Fe_2O_3	Recovery % Mont.	Wt. of Hematite in unfloc part in gm	Wt. of Mont. in unfloc in gm	Grade % Fe_2O_3	Grade % Mont.	Recovery % Fe_2O_3	Recovery % Mont.	
10	8.242	8.238	4.871	2.356	67.4	32.6	59.1	28.6	3.371	5.882	36.43	63.57	40.9	71.4	1.9
20	8.236	8.248	5.174	2.186	70.3	29.7	62.28	26.5	3.062	6.062	33.56	66.44	37.72	73.5	2.16
100	8.234	8.232	5.277	2.083	71.7	28.3	64.08	25.3	2.957	6.144	32.47	67.53	35.92	74.7	2.3
150	8.198	8.214	4.468	2.045	68.6	31.4	54.5	24.9	3.73	6.169	37.68	62.32	45.5	75.1	1.9

TABLE 39

Flocculation of synthetic Mixture (50:50) of Hematite-Montmorillonite (1-8 μ, Pulp density = 1) by MCH Starch = 40 PPM, pH = 9.5, Na_2SiO_3 = 100 PPM, Single Stage, time of settling = 1 minute, Mixing time for Na_2SiO_3 and NaF were 7 and 1 minutes respectively. (Vide Fig. 24)

Dosage of NaF in ppm	Total wt. of Hematite in gm	Total wt. of Mont. in gm	FLOCCULATED PART						UNFLOCCULATED PART						Selectivity Index
			Wt. of Hematite floc in gm	Wt. of Mont. in floc in gm	Grade		Recovery		Wt. of Hematite in unfloc part in gm	Wt. of Mont. in unfloc in gm	Grade		Recovery		
					% Fe_2O_3	% Mont.	% Fe_2O_3	% Mont.			% Fe_2O_3	% Mont.	% Fe_2O_3	% Mont.	
10	8.186	8.207	5.203	2.044	71.8	28.2	63.56	24.9	2.983	6.163	32.61	67.39	36.44	75.1	2.29
20	8.19	8.205	5.289	1.936	73.2	26.8	64.58	23.6	2.901	6.269	31.64	68.36	35.42	75.4	2.43
50	8.204	8.202	6.048	1.837	76.7	23.3	73.7	22.4	2.156	6.365	25.3	74.7	26.29	77.6	3.12
100	8.208	8.214	5.332	1.815	74.6	25.4	64.96	22.1	2.876	6.399	31.01	68.99	35.04	77.9	2.56

TABLE 40

Flocculation of Synthetic Mixture (50:50) of Hematite-Illite (1-8 μ, Pulp density = 1), pH = 7.3, MCH Starch is used. Time of settling = 1 minute, Single stage, (Vide Fig. 25)

Dosage of Starch in ppm	Total wt. of Hematite in gm	Total wt. of Illite in gm	FLOCCULATED PART: Wt. of Hematite floc in gm	Wt. of Illite in floc in gm	Grade % Fe_2O_3	Grade % Illite	Recovery % Fe_2O_3	Recovery % Illite	UNFLOCCULATED PART: Wt. of Hematite in unfloc part in gm	Wt. of Illite in unfloc in gm	Grade % Fe_2O_3	Grade % Illite	Recovery % Fe_2O_3	Recovery % Illite	Selectivity Index
20	8.008	8.004	4.659	2.553	64.6	35.4	58.18	31.9	3.349	5.451	38.06	61.94	41.82	68.1	1.72
40	8.024	4.932	4.932	2.418	67.1	32.9	61.46	30.2	3.092	5.588	35.62	64.38	38.54	69.8	1.92
60	8.016	8.018	4.849	2.453	66.4	33.6	60.49	30.6	3.167	5.565	36.27	63.73	39.5	69.4	1.86
80	8.022	8.020	4.533	2.430	65.1	34.9	56.51	30.3	3.489	5.59	38.43	61.57	43.49	69.7	1.73
100	8.038	8.024	4.495	2.463	64.6	35.4	55.93	30.7	3.543	5.561	38.92	61.08	44.07	69.3	1.69

TABLE 41

Flocculation of synthetic mixture (50:50) of Hematite-Illite (1-8 μ, Pulp Density = 1) by MCH Starch = 40 PPM, Time of Settling = 1 minute, Single Stage (Vide Fig. 26)

pH	Total wt. of Hematite in gm	Total wt. of Illite in gm	FLOCCULATED PART: Wt. of Hematite floc in gm	Wt. of Illite in floc in gm	Grade % Fe_2O_3	Grade % Illite	Recovery % Fe_2O_3	Recovery % Illite	UNFLOCCULATED PART: Wt. of Hematite in unfloc part in gm	Wt. of Illite in unfloc in gm	Grade % Fe_2O_3	Grade % Illite	Recovery % Fe_2O_3	Recovery % Illite	Selectivity Index
7.3	8.092	8.038	4.927	2.459	66.7	33.3	61.26	30.6	3.115	5.579	35.83	64.17	38.74	69.4	1.89
9.5	8.026	8.032	5.036	2.337	63.3	31.7	62.74	29.1	2.99	5.695	34.43	65.57	37.26	70.9	2.03
10.5	8.022	8.018	5.099	2.301	68.9	31.1	63.38	28.7	2.947	5.719	35.99	64.01	36.62	71.3	1.99

TABLE 42

Flocculation of Synthetic Mixture (50:50) of Hematite-Illite (1-8 μ, Pulp Density = 1) by MCH Starch = 40 PPM, pH = 9.5, Time of settling = 1 minute, Time for Na_2SiO_3 mixing = 7 minute Single Stage (Vide Fig. 27)

Dosage of Na_2SiO_3 in ppm	Total wt. of Hematite in gm	Total wt. of Illite in gm	FLOCCULATED PART						UNFLOCCULATED PART						Selectivity Index
			Wt. of Hematite floc in gm	Wt. of Illite in floc in gm	Grade		Recovery		Wt. of Hematite in unfloc part in gm	Wt. of Illite in unfloc in gm	Grade		Recovery		
					% Fe_2O_3	% Illite	% Fe_2O_3	% Illite			% Fe_2O_3	% Illite	% Fe_2O_3	% Illite	
10	8.046	8.020	5.099	2.301	68.1	31.1	63.38	28.7	2.947	5.719	35.99	64.01	36.62	71.3	1.99
50	8.042	8.036	4.979	2.113	70.2	29.8	61.9	26.3	3.063	5.923	34.09	65.91	38.1	73.7	2.14
100	8.056	8.036	5.585	1.993	73.7	26.3	69.32	24.8	2.471	6.043	29.02	70.98	30.68	75.2	2.618
150	8.046	8.048	4.890	1.939	71.6	28.4	60.17	24.1	3.156	6.109	34.06	65.94	39.83	75.9	2.21

Add$\overset{e}{\text{i}}$ndum

(1) Effect of pH : It seems that the effect of pH on flocculation of pure hematite is coupled with the presence of Na_2SiO_3 in the system. It seems that at high Na_2SiO_3 concentration, low pH (7.3) give optimum flocculation, while ~~at high pH coupled~~ with low Na_2SiO_3, higher pH gives better ~~gives optimum~~ flocculation.

(2) Particle size : For 1 pct. pulp density and 40 ppm initial starch concentration, we may set up a material balance equation for 1000 cc suspension system.

$$\underset{\text{(initial)}}{1.6 \times 10^{-8}} \text{ mole starch} = \underset{\text{residual}}{\text{residual ppm} \times 4\text{x}10^{-10}} + \underset{\text{on particle surface}}{\times\, \Gamma \cdot x}$$

where $x = 10^5$ for 1 µm hematite particle ($\rho = 5.63$ assumed spherical) and 10^4 for 10 µm particles.

Assuming that equilibrium has been attained $\Gamma = f$ (residual ppm) should correspond to the classical isotherm. For the equation to be balanced residual ppm can not be large. For example for 25 ppm residual, $\Gamma \times x$ is $\gg 1.6 \times 10^{-8}$. Hence residual ppm must be very small in which case

$$1.6 \times 10^{-8} \approx \Gamma \cdot x$$

For 1 µm particle, $\Gamma \simeq 1.6 \times 10^{-13}$ and 10 µm particle $\simeq 1.6\text{x}10^{-12}$ both being much less than saturation coverage. Near 100 pct. abstraction is indicated. However, whether equilibrium has been attained in few minutes is doubtful.

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